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Subject: Turbo-Alternator Design. See page 1, Section II

PROCEEDINGS
OF THE
American Institute
OF
Electrical Engineers

554746

VGA

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JANUARY, 1913

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American Institute

OF

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Regular January Meeting of the A. I. E. E. in New York, January 10, 1913

The two hundred and seventy-ninth meeting of the A. I. E. E. will be held in the auditorium of the Engineers Building, New York, January 10, 1913, at 8:15 p.m.

The meeting will be held under the auspices of the Power Station Committee, and a paper will be presented by Mr. B. G. Lamme entitled "High-Speed Turbo-Alternators—Designs and Limitations." The following gentlemen have been invited and are expected to participate in the discussion: Messrs. W. L. R. Emmet, W. J. Forster, H. M. Hobart, H. G. Reist, C. P. Steinmetz, H. B. Davis, Paul M. Lincoln, B. A. Behrend, C. A. Adams, W. C. L. Eglin, Peter Junkersfeld, C. J. Fechheimer, Philip Torchio, and W. F. Wells.

At the close of the technical session the meeting will adjourn to the Institute offices on the 10th floor, where the usual smoker will be held and light refreshments served.

Mid-Winter Convention February 26-28, 1913

The indications are that the Mid-winter Convention of the A. I. E. E., under the auspices of the Standards Committee, will be of great interest. A large number of papers are being prepared under the general direction of Dr. . E. Kennelly, chairman, and under the particular supervision of Messrs. Lamme and Steinmetz of the sub-committee on General Revision of Rules, and Messrs. Merrill, Robbins and Powell of the sub-committee on Rating. The convention will close with a reception and dance to be held at the Hotel Astor on Friday evening, February 28. A complete program of the convention will appear in the February PROCEEDINGS.

Acting Secretary Appointed

The sudden and unexpected illness of Secretary F. L. Hutchinson has made necessary the temporary appointment of an Acting Secretary, and at a special meeting of the Institute's Executive Committee held on December 18 in response to a call for that purpose, Mr. Ralph W. Pope was appointed to fill that office, in accordance with the following resolution:

> *Resolved*, that the Executive Committee, acting under Sections 44 and 45 of the Constitution of the Institute, hereby appoints Mr. Ralph W. Pope acting secretary during the illness of Mr. F. L. Hutchinson, in all duties devolving upon that official under the Constitution of the Institute, and authorizes him to draw and countersign all checks and drafts in payment of bills and vouchers approved by the Finance Committee and endorsed by the Treasurer as provided in Section 42 of the Constitution of the Institute. Mr. Pope's services as acting secretary are to continue until Mr. Hutchinson shall be able to resume his duties, or until other provision be made by the Board of Directors or by the Executive Committee acting for them.

For several weeks Mr. Hutchinson had been suffering from the grippe, and subsequently complications developed which are likely to keep him under a physician's care for several weeks.

Presentation of Papers at A. I. E. E. Meetings

The custom of having a smoker and sociable time after the technical sessions at the regular A. I. E. E. meetings in New York, renders the time available for discussion of papers somewhat limited. The value of a technical paper to the Institute membership is largely dependent upon the discussion of the paper from various points of view. In the past, the discussion has been farther limited owing to the amount of time spent in the reading of the papers by the authors.

It is believed that the general interest will be increased if the authors hereafter will prepare a digest of their papers which will not require over fifteen minutes for presentation. This digest should, of course, present in a concise manner the salient points of the paper and a rather full statement of the conclusions deduced.

The Meetings and Papers Committee, therefore, requests that hereafter each author will conform to this practise.

Nominations for Officers of the Institute

The attention of the membership is called to the modifications made last year in the method of making nominations for the various offices to be filled at the 1913 Institute election, whereby advance nominations may be made by petition so that when the official nomination forms are mailed to the membership on February 1, the names of candidates thus named in advance may appear on these forms, thereby affording the membership some guide as to the candidates who have been mentioned for the various offices.

This plan of making nominations provides a way for a group of members to suggest a candidate to the entire membership in an official manner, instead of by a circular letter which, under the former system, was practically the only effective means available.

The by-law governing the plan, as adopted by the Board of Directors on December 8, 1911, reads as follows:

> " SEC. 18. In addition to the names of the incumbents of office, the Secretary shall publish on 'the form showing offices to be filled at the ensuing annual election in May,' provided for in Article VI, Section 30, of the Constitution, the names, as candidates for nomination, of such members of the Institute as have been proposed for nomination for a particular office by the petition or by the separate endorsement of not less than fifty members, received by the Secretary of the Institute in writing by January 25 of each year.
>
> " The names of such candidates for nomination shall be grouped alphabetically under the name of the office for which each is proposed, and this by-law shall be reprinted prominently in the January issue of each year's PROCEEDINGS, and shall be reproduced on the form above referred to."

This plan was inaugurated last year, but as it could not be announced earlier than in the January PROCEEDINGS, and as all petitions had to be received at Institute headquarters not later than January 25, the time available for action was limited. The result, however, was a great improvement, in that the exceedingly large scattering vote that had been received in previous years was practically eliminated and the vote was largely concentrated upon candidates whose names had been suggested in advance.

As indicated above, petitions or separate endorsements of candidates must be received at Institute headquarters not later than January 25, 1913. Copies of the petition form may be obtained upon application to Institute headquarters, but the form is not necessary, as endorsements may be made by letter. The officers to be elected are a President, and a Treasurer, for a term of one year each; three Vice-Presidents, for a term of two years each; and four Managers, for a term of three years each.

Attention is also called to the following by-law relating to nomination forms.

"Sec. 19. Nomination forms, as provided in the Constitution, shall be sent, upon application, to members who have qualified between the dates of February 1 and March 1; and single copies only, of such nomination forms, shall be sent, upon request, as duplicates, to members who may have mislaid or destroyed their original copies. Nominations may, however, be written on blank paper if the regular form is not available."

A. I E. E. Meeting in New York December 13, 1912

The two hundred and seventy-eighth meeting of the Institute was held in the auditorium of the Engineering Societies Building, New York, Friday evening, December 13, 1912. President Ralph D. Mershon called the meeting to order at 8.15 o'clock.

The first paper, *High-Frequency Tests of Line Insulators*, by L. E. Imlay and Percy H. Thomas, was presented by Mr. Thomas. President Mershon then turned the remainder of the technical session over to Mr. Thomas, the chairman of the High-Tension Transmission Committee, under whose auspices the program had been arranged. The paper entitled *Comparative Tests on High-Tension Suspension Insulators*, by P. W. Sothman, was then presented by Mr. John A. Brundige, Mr. Sothman being away from the city at the time of the meeting. Mr. Brundige abstracted the paper and exhibited some slides showing fractures and punctures of insulators.

The two papers were discussed together, those taking part in the discussion being Messrs. Ralph D. Mershon, Paul M. Lincoln, F. W. Peek, Jr., J. A. Sandford, Jr., Percy H. Thomas, A. O. Austin, F. M. Farmer and Ralph W. Pope. The discussion closed with an interesting demonstration by Professor E. E. F. Creighton of actual breakdowns of pin and suspension-type insulators under high-tension, high-frequency tests. In closing the technical session, President Mershon invited further written discussion on the subject of the meeting, particularly on methods of testing. The members then adjourned to the Institute rooms on the tenth floor for the smoker.

Edison Medal Awarded to William Stanley

By the unanimous vote of all of the members of the Edison Medal Committee, the fourth Edison Medal was awarded on December 13, 1912, to William Stanley, electrical engineer and inventor, of Great Barrington, Mass., "for meritorious achievement in invention and development of alternating-current systems and apparatus." Arrangements for the formal presentation of the medal to Mr. Stanley will be announced later.

Directors' Meeting December 13, 1912

The Board of Directors of the American Institute of Electrical Engineers held its regular monthly meeting on Friday, December 13, 1912.

There were present, Ralph D. Mershon, President, New York; Gano Dunn, Past-President, New York; David B. Rushmore and Charles W. Stone, Schenectady, N. Y., A. W. Berresford, Milwaukee, Wis., William S. Murray, New Haven, Conn., W. G. Carlton and Severn D. Sprong, New York, Vice-Presidents; H. H. Barnes, Jr., W. S. Rugg, Charles E. Scribner, William McClellan, New York, F. S. Hunting, Fort Wayne, Ind., N. W. Storer, Pittsburgh. Pa., Comfort A. Adams, Cambridge, Mass., J. Franklin Stevens, Philadelphia, Pa., William B. Jackson, Chicago, Ill., Managers; George A. Hamilton, Treasurer, Elizabeth, N. J.; and F. L. Hutchinson, Secretary, New York.

The action of the Finance Committee in approving monthly bills, amounting to $9,726.23, was ratified.

The report of the Board of Examiners of its October, November and December meetings was read and accepted, and the action taken by the Board at those meetings was approved.

Upon the recommendation of the Board of Examiners, 55 applicants were elected Associates, and 119 students were ordered enrolled. Mr. Henry G. Stott was transferred to the grade of

Fellow under the regular provisions of the constitution.

Upon the approval of the Sections Committee, authority was granted for the organization of an Institute Branch at the University of Washington, Seattle, Washington, bringing the number of University Branches up to 46.

A request from the Pittsfield Section for an Institute meeting to be held in Pittsfield, Mass., in May, 1913, was laid over until the Meetings and Papers Committee could obtain further information.

A discussion upon the general subject of technical committees of the Institute, with particular reference to the appointment of additional committees for special fields of electrical engineering activity, resulted in the passage of a resolution authorizing the President to appoint a special committee to make a study of the entire subject of technical committees, some question having arisen as to the advisability of handling additional lines of work through new committees, or through sub-committees of the existing technical committees.

The President asked for the views of the Board in regard to the desirability of the Institute's taking up the subject of depreciation of electrical apparatus and machinery and the allied subjects of amortization, going value, etc.

There was considerable discussion on this question, which was considered of such importance that the President was authorized, in appointing the special committee to study the work of the technical committees, to refer to that committee the question of broadening the scope of the work of the Institute and the character and type of the papers to be presented.

The Electric Lighting Committee reported upon the Illuminating Engineering Society's primer on " Light," the publication of which the Institute had been asked to promulgate as far as possible. It was decided to give publicity to the primer by a special article to appear in the January PROCEEDINGS.

Reports were read from the Institute's representatives at the Fourth National Conservation Congress, Indianapolis, Ind., October 1-4, 1912, and the American Mining Congress, Spokane, Washington, November 25-28, 1912, and a recommendation from the delegation to the Conservation Congress that the Institute appoint a permanent representative upon the advisory board of the congress was referred to the Institute's Public Policy Committee.

The Library Committee reported that the recently amended by-laws of the United Engineering Society, providing for a new method of governing the united libraries of the three founder societies, call for the appointment of four members of the Institute, in addition to the Secretary, upon the Library Board. It was voted to refer this matter to the President with power.

Eighty-nine Associates, and eighty-eight Members, were transferred to the grade of Member and Fellow, respectively, in accordance with the provisions of the special section of the constitution.

International Electrotechnical Commission News

A meeting of the U. S. National Committee was held at the A. I. E. E. headquarters, December 13. At this meeting Past-President Henry G. Stott was appointed to represent the committee and the A. I. E. E. on a special international committee, to be known as " Committee on Prime Movers," which is to make a comprehensive study of the entire subject of prime movers, power stations, power costs, etc. The authoritative papers and discussions bearing upon these subjects contributed by Mr. Stott in the last ten years make him an authority on these subjects, and qualify him eminently to represent American practise and methods.

At this meeting various questions were considered which are to come up before forthcoming meetings of three committees of the International Electrotechnical Commission which will occur at Zurich next month (January

13 to 20). Mr. Mailloux, the president of the U. S. National Committee, was appointed to represent the U. S. National Committee at these meetings, and he is arranging to sail on December 31 for Europe. The A. I. E. E. Standards Committee has requested and authorized him to act as its representative in extending invitations to various electrical and electrotechnical societies abroad to send representatives to the mid-winter convention, at which important papers and discussions are to be presented on subjects of international importance and interest. Mr. Mailloux has also been requested and authorized by the Panama-Pacific Exposition authorities at San Francisco to represent its Bureau of Conventions and Societies, and to extend formal invitations to various scientific and engineering societies to come to San Francisco in 1915 to hold their annual conventions or meetings.

Light—Its Use and Misuse

Under the above title, the Illuminating Engineering Society has prepared a primer of illumination setting forth in simple and concise style the general principles to be followed in the application of artificial illumination, whether produced by oil, gas, electricity or otherwise.

The book, which covers 20 pages of the size of the PROCEEDINGS, is designed to place before the public simple information regarding the fundamental requirements to be observed in the correct use of artificial illuminants. It is profusely illustrated with examples of both good and poor lighting, so that the illustrations alone tell the story even without the help of the text.

The primer is not to be regarded as a treatise for the electrical engineer, but rather as a reminder to the public, to which it is addressed, of many facts and principles which are very generally understood but which are nevertheless frequently ignored, more through carelessness than ignorance. Everyone knows, for example, that light should be directed upon the work and not into the eyes of the worker, yet this simple rule is very frequently disregarded to the discomfort of the worker and to the detriment of the work.

The subject of artificial illumination is considered from an artistic as well as from a utilitarian standpoint. It is often necessary to sacrifice strict economy to obtain the most pleasing decorative or artistic effects, but it is of interest to know that good lighting, from the standpoint of utility, is often less costly than poor lighting, because with a suitable arrangement a larger proportion of the light is utilized and less is wasted.

The primer contains many very useful hints to users of artificial illumination, and copies of it may be obtained at the price of 10 cents each by addressing the Secretary of the Illuminating Engineering Society, 29 West 39th Street.

Standardization of Conduit Construction

The growing use of metallic conduit for the installation of wires in buildings, and the frequent tendency to use conduits of too small interior diameter, have led the National Electrical Contractors Association to prepare data in regard to the proper size of conduit to be used in installing wire and cables. The result of the investigation of this subject by the Association is embodied in six charts showing in full size the proper sizes of conduits to be used for the installation of numerous combinations of wires and cables. These charts were officially adopted at the 12th annual meeting of the National Electrical Contractors Association.

In addition to showing the proper size conduit for combinations of wires, the charts give the actual exterior diameter of the conduit and the carrying capacity of the wires shown, which covers practically all of the information required for the installation of wires and conduits. These charts are furnished by the N. E. C. A. at $2.25 a set, which is the actual cost of reproduction, and further information can be obtained on application to W. H. Morton, secretary of the Association, 41 Martin Building, Utica, N. Y.

Future Section Meetings

CHICAGO

At a meeting of the Chicago Section to be held on January 27, a paper on "The Principles of Regulation and Methods by which the Public Utility Laws are Enforced" will be presented by Mr. Alfred Ericson, a member of the Railway Commission of Wisconsin. There is considerable agitation in Illinois at this time as to whether or not it is more desirable to have one Public Utility Commission for the entire State, or two commissions, one for the State at large and an entirely separate body for Cook County and the City of Chicago, so that Mr. Ericson's subject is a very timely one.

Associates Elected December 13, 1912

ALDRIDGE, ARTHUR P., Operating Engineer, Dunedin City Corporation, Waipori Power Station, Waipori Falls, Otago, N. Z.

BANHOLZER, HERWIN S., Electrical Engineer, Newport Rolling Mill Co.; res., 516 West 9th St., Newport, Ky.

BEDIANT, EARLE WENDELL, Draftsman, Pittsburgh Rys. Co., and Allegheny County Light Co., Pittsburgh, Pa.

BISHOP, LEON W., Electro-mechanic, 100 Boylston St.; res., 18 Irving St., Boston, Mass.

CARROLL, JOHN GUSTAVE, Electrical Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh; res., 413 Pitt St., Wilkinsburg, Pa.

CATES, BENNETT E., Operator, Hydro-Electric Station, Trinity Dredging Co., Minersville, Cal.

COOK, JOHN, Mechanical Engineer, Cook & Cook, Victor Bldg., Washington, D.C.

CRESSMAN, JOHN ALBERT, Electrical Tester, Crocker-Wheeler Co., Ampere; res., 107 N. 14th St., East Orange, N. J.

CURRIE, NEIL, JR., Electrical Engineer, General Electric Co., Pittsfield, Mass.

DIEDERICH, PETER, Construction Foreman, Light Dept., City Hall; res., 121 Belmont St., Glendale, Cal.

DOLBEAR, BENJAMIN L., Telephone Engineer, New England Tel. & Tel. Co., 50 Oliver St., Boston; res., 14 Wyman St., Arlington, Mass.

DRYDEN, HARRY WALTER, Chief Operator, Cauvery Power Scheme, Mysore, India.

ELLIS, G. EVERETT, JR., Assistant to Chief Electrical Engineer, Edison Storage Battery Co.; res., 150 Chestnut St., West Orange, N. J.

EVANS, EVAN, Chief Engineer, Hydro-electric System, Hawera Electric Lt. & Pr. Co., Hawera, Taranaki, N. Z.

FOWLER, JOHN, Representative, Maine Electric Co. of Portland, Me., 165 Broadway, New York, N. Y.

FRIEND, LEONARD L., Chief Electrician and Mechanic, No. 3 Mine, United States Gypsum Co., Oakfield, N. Y.

FULLER, WILLIAM JAMES, Construction Foreman, Pacific Gas & Electric Co., 445 Sutter St.; res., 2218 H. St., Sacramento, Cal.

GALLANT, WADE M., Salesman, Westinghouse Electric & Mfg. Co., Charlotte, N. C.

HECKSHER, S. H., Electrical Inspector, Mexican Light & Power Co., Apartado 124, Mexico, D. F.

HODGE, WILLIAM WASHINGTON, Asst. Supt. Elec. Cable Works, American Steel & Wire Co.; res., 3 Berkmans St., Worcester, Mass.

HOLCOMBE, ERNEST SELAH, Assistant Engineer, Electric Bond & Share Co., 71 Broadway; res., 269 West 12th St., New York, N. Y.

IRVING, GUGY AE., JR., Electrical Inspector, Board of Public Utility Commissioners, 738 Broad St.; res., 23 Franklin St., Newark, N. J.

JACOBSON, SAMUEL OSCAR, Electrical Engineer and Contractor, Electric Construction Co., 50 West St., New York, N. Y.

Janes, Arthur Gross, Chief Electrician, Pittsburgh Plate Glass Co., Kokomo, Ind.

Johnson, Carl Edwin, Operator, Northern California Power Co., Inskip Power House, Manton, Cal.

Johnson, Earl Stimpson, Electrical Engineer, General Electric Co.; res., 121 Glenwood Blvd., Schenectady, N. Y.

Kammerman, John Oscar, Instructor in Electrical Engineering, Pennsylvania State College, State College, Pa.

Kline, Alexander Dorn, Designing Engineer, Railway & Traction Engg. Dept., General Electric Co., Schenectady, N. Y.

Lythgoe, Joseph, Mains Engineer, Electrical Dept., Dunedin City Corporation, Dunedin, N. Z.

McCoy, Louis Edwin, Electrical Construction Dept., Portland Ry. Lt. & Pr. Co.; res., 675 E. Glisan St., Portland, Ore.

McCuaig, Oliver Bain, Superintendent in Charge, Wenatchee Valley Gas & Electric Co., Wenatchee, Wash.

Metz, Ora Franklin, Erecting Engineer, Allis-Chalmers Co.; res., 645 Milwaukee St., Milwaukee, Wis.

Miller, Frederick, Student Engineer, General Electric Co.; res., 15 Mall St., Lynn, Mass.

Montgomery, John Harold, Associate Professor of Electrical Engineering, University of Southern California, Los Angeles, Cal.

Ober, Ralph Hadlock, Superintendent of Buildings, 222 City Hall, Seattle, Wash.

Oesterlein, Wilhelm Joseph, Designing Engineer, Northwestern Manufacturing Co.; res., 596 Jackson St., Milwaukee, Wis.

Pierce, Leonard G., Electrical Testing Laboratories, 80th St. & East End Ave.; res., 257 West 129th St., New York, N. Y.

Rao, M. G. Ramachandra, Assistant Superintendent, Government Industrial School, Mysore, India.

Reinbold, Robert, Superintendent of Inside Construction, Consumers Power Co., 76 West 3rd St.; res., 666 Ottawa Ave., St. Paul, Minn.

Rowe, George Nicolas Waldron, City Civil and Electrical Engineer, Potosi, Bolivia, S. A.

Rusher, Merlin A., Student Engineer, General Electric Co.; res., 170 Nott Terrace, Schenectady, N. Y.

Sawyer, Harold Moore, Power Engineer, Scranton Electric Co.; res. 416 Chemung St., Waverly, N. Y.

Schaller, William Fred, Electrical Engineer, Edison Electric Illuminating Co., Brooklyn; res., 257 West 129th St., New York, N. Y.

Shelton, Edward K., Electrical Engineer, General Electric Co.; res., 211 Seward Place, Schenectady, N.Y.

Stein, Arthur L., Engineer, Electrical Dept., D. L. & W. R. R.; res., 307 Madison Ave., Scranton, Pa.

Streich, Harry C., Electrical Engineer, with City Chemist, Room 83, Court House, St. Paul, Minn.

Taylor, George Otis, Traveling Toll Wire Chief, Southern Bell Tel. & Tel. Co., Atlanta, Ga.

Thompson, George Silas, Chief Electrician, Fuel Dept., Colorado Fuel & Iron Co., Pueblo, Colo.

Thompson, Jesse Lysander, Inspector, Electric Department, St. Paul Gas Light Co.; res., 1680 Capitol Ave., St. Paul, Minn.

Troop, George J., Jr., Purchasing Agent, Mexican Tramways Co., and Mexican Light & Power Co., Mexico, D. F.

Van Bokkelen, William Regua, Assistant to General Manager, Coast Counties Gas & Electric Co , San Francisco; res., 3028 Benvenue Ave., Berkeley, Cal.

Welch, Alfred Francis, Electrical Engineer, Fort Wayne Electric Works; res., 344 West Woodland Ave., Fort Wayne, Ind.

Wells, Walter Todd, Superintendent and Chief Engineer, Iloilo Electric Co., Inc., Iloilo, P. I.

Whitham, Albert, Draftsman, Mexican Light & Power Co.; res., 6a Ayuntamiento 138, Mexico, D. F.

Whitman, Chester Wilson, Telephone and Signal Engineer, Room 324, 171 Westminster St., Providence, R. I.

Total, 55

Transferred to Grade of Fellow, December 13, 1912

The following were transferred to the grade of Fellow of the Institute at the meeting of the Board of Directors on December 13, 1912:

RECOMMENDED FOR TRANSFER BY THE BOARD OF EXAMINERS

Stott, Henry G., Superintendent Motive Power, Interborough Rapid Transit Co., New York., N. Y.

TRANSFERRED IN ACCORDANCE WITH THE SPECIAL SECTION OF THE CONSTITUTION

Albright, H. Fleetwood, General Superintendent, Western Electric Co., New York, N. Y.

Arnold, Bion J., Consulting Electrical Engineer, Chicago, Ill.

Babcock, A. H., Electrical Engineer, Harriman Lines, San Francisco, Cal.

Bancroft, Charles F., Electrical Engineer, Massachusetts Electric Companies, Boston, Mass.

Barnum, Thomas Edson, Chief Engineer, Cutler-Hammer Mfg. Co., Milwaukee, Wis.

Barton, Philip P., Vice-President and General Manager, Niagara Falls Power Co., Niagara Falls, N. Y.

Blood, John Balch, Consulting Engineer, Newburyport, Mass.

Bogen, Louis E., Chief Electrical Estimating Engineer, Allis-Chalmers Co., Milwaukee, Wis.

Boyer, Elmer E., Electrical Superintendent, General Electric Co., West Lynn, Mass.

Burleigh, Charles B., District Manaager Lighting Dept., General Electric Co., Boston, Mass.

Coldwell, Orin B., General Superintendent, Portland Railway, Light & Power Co., Portland, Ore.

Colpitts, E. H., Research Engineer, Western Electric Co., New York, N. Y.

Comstock, L. K., President, L. K. Comstock Co., Inc., New York, N. Y.

Conklin, L. H., Secretary-Treasurer and General Manager, United Service Co., Scranton, Pa.

Corey, Fred B., Engineer of Inspection and Tests, Union Switch & Signal Co., Swissvale, Pa.

Cowles, Alfred H., President, Electric Smelting & Aluminum Co., Sewaren, N. J.

Crawford, David F., General Superintendent Motive Power, Pennsylvania Lines, West, Pittsburgh, Pa.

Cushing, Harry C., Jr., Publisher and Editor, " The Central Station," and " Standard Wiring," New York, N.Y.

Dean, William T., District Manager, Power and Mining Dept., General Electric Co., Chicago, Ill.

Doane, Samuel E., Chief Engineer, National Electric Lamp Association, Cleveland, Ohio.

Dunlap, W. K., Assistant to Vice-President, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.

Faccioli, G., Assistant Engineer, Transformer Dept., General Electric Co., Pittsfield, Mass.

Farrand, Dudley, General Manager, Public Service Electric Co., Newark, N. J.

Ferguson, Louis A., Second Vice-President, Commonwealth Edison Co., Chicago, Ill.

Field, Stephen D., Electrical Engineer, Stockbridge, Mass.

Foster, Horatio A., Valuation of Public Utilities, J. G. White & Co., Toronto, Ont.

Fynn, Valere A., Consulting Engineer, Wagner Electric Mfg. Co., St. Louis, Mo.

Gherardi, Bancroft, Engineer of Plant, American Telephone & Telegraph Co., New York, N. Y.

Hammer, Edwin W., Consulting Engineer, New York City.

Hammer, William J., Consulting Electrical Engineer, New York, N. Y.

Hayward, R. F., Chief Engineer and General Manager, Western Canada Power Co., Ltd., Vancouver, B. C.

Herdt, L. A., Head of Electrical Engineering Dept., McGill University, Montreal, Que.

Herrick, Charles H., New England Representative, National Meter Co., Boston, Mass.

Hobart, Henry M., Consulting Engineer, General Electric Co., Schenectady, N. Y.

Hooper, William L., Professor of Electrical Engineering, Tufts College, Mass.

Hosmer, Sidney, In charge of Construction Work, Edison Electric Illuminating Co., Boston, Mass.

Howell, John W., Engineer, Lamp Works, General Electric Co., Newark, N. J.

Insull, Samuel, President, Commonwealth Edison Co., Chicago, Ill.

Jackson, Dugald C., Professor of Electrical Engineering, Consulting Engineer, Massachusetts Institute of Technology, Boston, Mass.

Jewett, Frank B., Assistant Chief Engineer, Western Electric Co., New York, N. Y.

Jones, George H., Power Engineer, Commonwealth Edison Co., Chicago, Ill.

Junkersfeld, Peter, Assistant to 2nd Vice-President, Commonwealth Edison Co., Chicago, Ill.

Karapetoff, Vladimir, Professor of Electrical Engineering, Cornell University, Ithaca, N. Y.

Kelsch, R. S., Consulting Engineer, Montreal, Canada.

Koiner, C. W., General Manager and Electrical Engineer, Pasadena Municipal Light Dept., Pasadena, Cal.

Langsdorf, Alexander S., Professor of Electrical Engineering, Washington University, St. Louis, Mo.

Layman, W. A., President and General Manager, Wagner Electric Mfg. Co., St. Louis, Mo.

Lord, Charles E., General Patent Attorney, International Harvester Co., Chicago, Ill.

Luck, Fred J. W., Representative, Westinghouse Electric & Mfg. Co., Brazil, S. A.

Moody, Walter S., Chief Engineer, Transformer Dept., General Electric Co., Pittsfield, Mass.

Moses, Percival R., Consulting Engineer, New York, N. Y.

Motter, W. N., Engineer in charge of Direct Current Design, Allis-Chalmers Co., Milwaukee, Wis.

Mudge, A. L., Chief Electrical Engineer, Smith, Kerry & Chace, Toronto, Ont.

Murray, Thomas E., Second Vice-President and General Manager, New York Edison Co., New York, N. Y.

Newbold, R. M., Electrical Engineer, Adams & Westlake Co., Chicago, Ill.

Nims, Frederick D., Electrical Enggineer, Western Canada Power Co., Vancouver, B. C.

Osborn, Joseph A., Chief Electrical Engineer, American Car & Foundry Co., St. Louis, Mo.

Paine, Sidney B., Manager Mill Power Dept., General Electric Co., Boston, Mass.

Peck, J. S., Consulting Electrical Engineer, British Westinghouse Electric & Mfg. Co., Manchester, England.

PenDell, C. W., Engineer, Contract Dept., Public Service Co. of Northern Illinois, Chicago, Ill.

Perry, Leslie L., Electrical Engineer, Sargent and Lundy, Chicago, Ill.

Pickard, Greenleaf W., Consulting Electrical Engineer, Amesbury, Mass.

Powell, William H., Electrical Engineer in Charge, Allis-Chalmers Co., Milwaukee, Wis.

Rippey, S. Howard, Consulting Engineer, Germantown, Pa.

Robinson, J. K., Electrical Engineer and Agent, Westinghouse Electric & Mfg. Co., West Coast of South America, New York, N. Y.

Roehl, C. E., Electrical Engineer, Brooklyn Rapid Transit System, Brooklyn, N. Y.

Rosenbusch, Gilbert, Consulting Engineer, London, S. W., England.

Ross, J. D., Superintendent of Lighting, Seattle, Wash.

Ross, Norman N., District Steam Turbine Specialist, General Electric Co., Cincinnati, Ohio.

Ross, R. A., Consulting Engineer, Montreal, Can.

Ruffner, Charles S., General Manager, Mississippi River Power Distributing Co., St. Louis, Mo.

Sachs, Joseph, Vice-President and General Manager, The Sachs Laboratories, Inc., Hartford, Conn.

Sargent, F. C., Engineering Manager, Charles H. Tenney & Co., Boston, Mass.

Sawtelle, E. M., Consulting Engineer, New York, N. Y.

Scheffler, Frederick A., Sales Engineer, Babcock & Wilcox Co., New York, N. Y.

Sharp, Clayton H., Test Officer, Electrical Testing Laboratories, New York, N. Y.

Shover, Barton R., Superintendent, Brier Hill Steel Co., Youngstown, Ohio.

Sinclair, H. A., Electrical Engineer and Secretary-Treasurer, Tucker Electrical Co., New York, N. Y.

Skinner, Charles E., Engineer, Research Division, Westinghouse Electric & Mfg. Co., Pittsburgh, Pa.

Stillwell, Lewis B., Consulting Engineer, New York, N. Y.

Taylor, William T., Consulting Engineer, Santiago, Chile, S. A.

Timmerman, A. H., Chief Engineer, Wagner Electric Mfg. Co., St. Louis, Mo.

Townley, Calvert, Assistant to President, Westinghouse Electric & Mfg. Co., New York, N. Y.

Wheeler, Schuyler Skaats, President, Crocker-Wheeler Co., Ampere, N. J.

Wilcox, Norman T., Manager and Special Agent, Stone & Webster Engg. Corp'n., Boston, Mass.

Williamson, R. B., Electrical Engineer, Allis-Chalmers Co., Milwaukee, Wis.

Wood, George R., Electrical and Mechanical Engineer, Berwind-White Coal Mining Co., and Consulting Electrical Engineer, Ragstown Water Power Co., Philadelphia, Pa.

Worth, B. G., Electrical Engineer, with Walter Kidde, New York, N. Y.

Total 89.

Transferred to Grade of Member, December 13, 1912

The following Associates were transferred to the grade of Member of the Institute at the meeting of the Board of Directors on December 13, 1912:

TRANSFERRED IN ACCORDANCE WITH THE SPECIAL SECTION OF THE CONSTITUTION

Alkins, Albert E., Assistant to Electrical Superintendent, General Electric Co., Lynn, Mass.

Allen, Elbert G., Superintendent of Construction, Stone & Webster Engg. Corp'n., Seattle, Wash.

Bates, Frederick C., District Manager Lighting Dept., General Electric Co., New York, N. Y.

Berry, Edward R., Chemical Engineer, Malden, Mass.

Brainard, F. K., Electrical Engineering Dept., Allis-Chalmers Co., Milwaukee, Wis.

Brandon, Edgar T. J., Assistant Engineer, Hydro-Electric Power Commission, Toronto, Ont.

Button, Arnold E., General Electric Co., Schenectady, N. Y.

Byllesby, H. M., President, H. M. Byllesby & Co., Chicago, Ill.

Carter, Wilson A., Assistant Superintendent Electrical Dept., Denver Gas & Elec. Light Co., Denver, Colo.

Clark, Farley G., Chief Engineer, Toronto Power Co., Toronto, Ont.

Clarkson, S. N., Power Engineer, Union Electric Light & Power Co., St. Louis, Mo.

Cole, G. Percy, Chief Estimating Engineer, Allis-Chalmers-Bullock, Ltd., Montreal, Que.

Coulter, L. P., Electrical Engineer, Cutler-Hammer Mfg. Co., Milwaukee Wis.

Crocker, J. R., Consulting Engineer, Warner Chemical Co., and Keystone Chemical Mfg. Co., New York.

Darbee, William, Electric Bond & Share Co., New York, N. Y.

Davis, G. Sanford, Canadian General Electric Co., Toronto, Ont.

Davis, Solomon, President, Conduit Wiring Co., New York, N. Y.

Davis, William J., Jr., Engineer, Pacific Coast District, General Electric Co., San Francisco, Cal.

De Wolf, R. D., Assistant Mechanical Engineer, Rochester Railway & Light Co., Rochester, N. Y.

Dodge, Kern, Consulting Engineer, Philadelphia, Pa.

Durant, William C., General Superintendent, Prince Rupert Hydro-Electric Co., Prince Rupert, B. C.

Farrar, Edward L., Sales Agent, General Electric Co., Pittsburgh, Pa.

Fielding, George T., Electrical Advertising Devices, New York, N. Y.

Foley, H. S., General Inspector, Mexican Light & Power Co., Mexico, D. F. Mex.

Freund, Mortimer, General Engineer, with Percival R. Moses, New York, N. Y.

Fullerton, Hugh L., Electrical Engineer, Allegheny County Light Co., Pittsburgh, Pa.

Gaillard, L. L., Vice-President and General Manager, New England Engineering Co., New York, N. Y.

Gibson, John J., District Manager, Westinghouse Electric & Mfg. Co., Philadelphia, Pa.

Glines, E. Stanley, Assistant Chief Draftsman, Stone & Webster Engg. Corp'n., Boston, Mass.

Goodspeed, M. C., General Electric Co., Erie, Pa.

Gray, Charles F., Consulting Electrical Engineer, Winnipeg, Manitoba.

Green, F. C., Transformer Engineering Dept., General Electric Co., Pittsfield, Mass.

Hall, H. Y., Assistant Electrical Engineer, Southern Pacific Co., San Francisco, Cal.

Harding, C. Francis, Head Professor of Electrical Engineering and Director of Electrical Laboratories, Purdue University, Lafayette, Ind.

Havill, O. A., Electrical Engineer, Viele, Blackwell & Buck, New York, N. Y.

Hawley, Kent A., Assistant Superintendent of Electric Construction, Appalachian Power Co., Pulaski, Va.

Higbie, Henry H., Head of Electrical Departments, Wentworth Institute, Boston, Mass.

Hipple, J. M., Engineer, Industrial Division, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Hobble, Arthur C., Electrical Construction Engineer, Mexican Northern Power Co., Santa Rosalia, Chih., Mex.

Hobbs, Henry W., Principal Assistant Engineer, U. S. Engineer Office, Portland, Me.

Hoffmann, Bernhard, Consulting Engineer, Chicago, Ill.

Houskeeper, William G., Philadelphia, Pa.

Hutchings, James T., General Manager, Rochester Railway & Light Co., Rochester, N. Y.

Johann, Charles S., Commercial Manager and Assistant Chief Engineer, L. M. & W. P. Ry. Co., Milton, Pa.

Johnson, Lester G., Commercial Engineer, General Electric Co., Schenectady, N. Y.

Kilbourne, C. G., Assistant to Chief Electrical Engineer, New York Edison Co., New York, N. Y.

Krass, Ralph W., Cable Engineer, New York Edison Co., New York, N. Y.

Lamke, George W., Assistant Professor of Electrical Engineering, Washington University, St. Louis, Mo.

LAVINE, SAUL, Switchboard Specialist, General Electric Co., Pittsburgh, Pa.

LAWRENCE, W. H., Superintendent Waterside Stations, New York Edison Co., New York, N. Y.

LEMMON, G. N., Assistant Chief Engineer, Mahoning & Shenango Railway & Light Co., Youngstown, Ohio.

MAGALHAES, F. V., Superintendent, Meter Dept., New York Edison Co., New York, N. Y.

MATHER, EUGENE H., Public Service Corporation Expert, Boston, Mass.

MATTHEWS, CLAUDE L., Partner and Electrical Engineer, W. N. Matthews & Bro., St. Louis, Mo.

MAXWELL, ALEXANDER, Chief of Laboratory, New York Edison Co., New York, N. Y.

McCANN, WILLIAM R., Assistant Engineer, Isthmian Canal Commission, Culebra, C. Z.

McCONAHEY, W. M., Head of Transformer Div., Engg. Dept., Westinghouse Electric & Mfg. Co., Pittsburgh Pa.

McFEDRIES, SHERMAN M., Manager Controller Sales, Cutler-Hammer Mfg. Co., Milwaukee, Wis.

McKEE, ROBERT A., Manager, Steam Turbine Dept., Allis Chalmers Co., Milwaukee, Wis.

MERRILL, G. S., Assistant to Chief Engineer, National Electric Lamp Association, Cleveland, Ohio.

MILLS, JOHN, Engineering Dept., American Tel. & Tel. Co., New York, N.Y.

MORTENSEN, SOREN H., Electrical Engineer, Allis-Chalmers Co., Milwaukee, Wis.

PACK, ROBERT F., General Manager, Minneapolis General Electric Co., Minneapolis, Minn.

PAINE, ELLERY B., Assistant Professor of Electrical Engineering, University of Illinois, Urbana, Ill.

PATTISON, HUGH, Electrical Engineer, Chicago Ass'n. of Commerce, Chicago Ill.

PAULY, KARL A., Power & Mining Dept., General Electric Co., Schenectady, N. Y.

PEARSON, EDWIN R., General Electric Co., Pittsfield, Mass.

PETURA, FRANK J., Electrical and Gas Engineer, and Purchasing Agent, H. L. Doherty & Co., New York, N.Y.

PIERCE, CLARENCE A., Assistant Professor of Theoretical Electrical Engineering, Worcester Polytechnic Institute, Worcester, Mass.

RANDALL, K. C., Engineer in charge of Switchboard Division, Westinghouse Electric & Mfg. Co., Pittsburgh, Pa.

RICE, RALPH H., Assistant Electrical Engineer, Board of Supervising Engineers, Chicago Traction, Chicago, Ill.

RODMAN, WALTER SHELDON, Adjunct Professor of Electrical Engineering, University of Virginia, University, Va.

ROUX, GEORGE P., Electrical Engineer, Day & Zimmerman, Philadelphia, Pa.

RYAN, WILLIAM T., Assistant Professor of Electrical Engineering, University of Minnesota, Minneapolis, Minn.

SANDERSON, C. HERBERT, Electrical Engineer. General Engg. Div., Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

SANVILLE, HENRY F., Consulting Engineer, Philadelphia, Pa.

STUTZ, C. C., Consulting Engineer, Norwood, Ohio.

THOMAS, STEPHEN A., Chief of Electrical Division, Building Bureau, Dept. of Education, New York, N. Y.

TIMBIE, WILLIAM H., Head of Applied Science Dept., Wentworth Institute, Boston, Mass.

TOPPING, ALANSON N., Professor of Electrical Engineering, Purdue University, Lafayette, Ind.

TOWN, FREDERIC E., Local Manager, Otis Elevator Co., Pittsburgh, Pa.

WALDO, EDWARD H., Assistant Professor of Electrical Engineering, University of Illinois, Urbana, Ill.

WATROUS, CLEVELAND, Manager, Cutler Hammer Mfg. Co., New York, N. Y.

WEBB, HENRY STORRS, Principal, Schools of Telephony and Telegraphy, International Correspondence School, Scranton, Pa.

Wilkinson, Nathan, Engineer, Direct-Current Apparatus, Allis-Chalmers Co., Milwaukee, Wis.

Wilson, Percy J., Electrical Engineer, Lowell Electric Light Corp'n., Lowell, Mass.

Woodruff, L. S., Electrical Engineer, Allis-Chalmers Co., Norwood, Ohio.

Wynne, Francis E., Engineer Railway Section, Westinghouse Electric & Mfg. Co., Pittsburgh, Pa.

Zachau, Carl E., Electrical Engineer, Shaw Electric Crane Co., Muskegon, Mich.

Total 89.

Recommended for Transfer to Grade of Fellow, December 5, 1912

The following members were recommended for transfer to the grade of Fellow by the Board of Examiners at its regular monthly meeting held on December 5, 1912. Any objection to these transfers should be filed at once with the Secretary:

Blathy, Otto T., Advising Engineer, Ganz Electric Co., Budapest, Hungary.

Hopkins, Nevil Monroe, Consulting Electrical Engineer, Washington, D. C.

Lancaster, W. C., Electrical and Mechanical Engineer, Canadian Northern Tunnel and Terminal, Montreal, Que.

Rhodes, Frederick L., Outside Plant Engineer, American Tel. & Tel. Co., New York, N. Y.

Addresses Wanted

Name	Former address
G. M. Dyott,	50 Church St., New York, N.Y.
S. B. Mambert,	288 Broadway, Kingston, N. Y.
Raymond Whiteley,	Antofagasta, Chile, S. A.

Anyone who can give information that may assist in obtaining any of these addresses is requested to communicate with the secretary of the Institute.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute as Associates. In cases where the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before January 25, 1913.

Anderson, W. H., Brooklyn, N. Y.
Annett, F. A., Richmond Hill, N. Y.
Backstrand, C. F., Berkeley, Cal.
Barnard, R. B., Butte, Mont.
Bassett, J. B., Schenectady, N. Y.
Beebe, L. H., Los Angeles, Cal.
Beekman, R. A., Schenectady, N. Y.
Belsky, C. J., Madison, Wis.
Berry, W. N., Albuquerque, N. M.
Boright, G. K., Montreal, Que.
Bower, G. W., Schenectady, N. Y.
Bowes, L. C., Ithaca, N. Y.
Bradford, P. L., Erie, Pa.
Branson, E. H., Schenectady, N. Y.
Brunn, G. T., Wilkinsburg, Pa.
Cantin, A. J., Edmonton, Alta.
Carlson, A., Chicago, Ill.
Catlin, W. G., Ithaca, N. Y.
Chinlund, J. F., Chicago, Ill.
Clarkson, R. P., Wolfville, N. S.
Cleveland, C. E., Portland, Ore.
Cogswell, F. R., Pittsburgh, Pa.
Coxon, G. H., Vera Cruz, Mex.
Darrow, R. C., New York, N. Y.
de Romana, A. L., Schenectady, N. Y.
de Windt, J. P. H., Jr., Saybrook Junction, Conn.
Doane, R. E., Pittsburgh, Pa.
Dobson, W. P., Toronto, Ont.
Du Bois, T. R., Niagara Falls, N. Y.
Dushman, S., Schenectady, N. Y.
Fraser, A. S., Smith's Falls, Ont.
Goodwin, P. H., Williamson, W. Va.
Gordon, V. D., Mexico City, D. F.
Gundlach, W. E., Milwaukee, Wis.
Hackenberg, H. J. A., Cleveland, O.
Hall, E. J. C., Yonkers, N. Y.
Hart, J. P., Portland, Ore.
Hartzell, R. C., Columbus, Ohio.
Hemmenway, L. T., Brooklyn, N. Y.
Henrichsen, C., Pittsfield, Mass.

Hoffman, H. A., Schenectady, N. Y.
Holden, E., Vancouver, B. C.
Humphrey, G. S., Salt Lake City, Utah.
Jeffery, R. T., Toronto, Ont.
Jeffrey, C. S., Rangoon, India.
Jesperson, C. M., Charleston, W. Va.
Kaplan, E. V., Connellsville, Pa.
Keeler, H. E., Ann Arbor, Mich.
Kent, S. B., Cicero, Ill.
Kidd, Andrew, Jr., (Member). New York, N. Y.
Kobrock, J. P., St. Joseph, Mo.
Lamb, C. H., Chicago, Ill.
Lamberton, H. C., Fayetteville, Ark.
Long, G. J., Lehigh, Iowa.
Lufkin, F. R., Boston, Mass.
Martin, E. R., New Haven, Conn.
Mayo, C. A., Oswego, N. Y.
Mayott, C. W., Hartford, Conn.
McDowell, T. S., Mexico, D. F.
McKechnie, W. E., Detroit, Mich.
Moore, E. B., Springfield, Vt.
Morris, H. T., Wilkinsburg, Pa.
Moyer, L. M., Schenectady, N. Y.
Nash, Herbert, Jr., (Member), Boston, Mass.
Neumann, S. G., Minneapolis, Minn.
Palmer, J., Hamilton, Ont.
Prince, E., Chicago, Ill.
Ramey, B. B., Ampere, N. J.
Ramsay, J. W., Austin, Texas.
Riggs, L. W., Schenectady, N. Y.
Roberts, D. A., Springfield, Ill.
Rogers, F., Jr., Springfield, Mass.
Schirmer, A. H., Newark, N. J.
Scrivener, R. M., Toronto, Ont.
Shepard, J. A., Tucson, Ariz.
Short, F., Ithaca, N. Y.
Silsbee, F. B., Washington, D. C.
Skipworth, L. W., New York, N. Y.
Smith, A. V., Ashtabula, Ohio.
Smith, H. E., Schenectady, N. Y.
Smith, P. R., Pittsfield, Mass.
Smith, S. E. H., Vancouver, B. C.
Snider, R. A., Winber, Pa.
Speight, H., Anyox, B. C.
Standing, A. J., So. Bethlehem, Pa.
Stevenson, T. K., New York, N. Y.
Sticht, H. H., New York, N. Y.
Stickney, H. R., Leominster, Mass.
Sunnergren, A. P., Wilkinsburg, Pa.
Taylor, A. B., Wahpeton, N. D.
Thomen, M. K., Joplin, Mo.
Treweeke, F. L., Mexico, D. F.
Trout, B. R., Great Falls, Mont.
Twaddle, H. L., Ft. Lincoln, N. D.
Vinet, E., Outremont, P. Q.
Wade, G. W., Pittsfield, Mass.
Walker, D. I., Victoria, B. C.
Weston, George, (Member), Chicago, Ill
Wheelock, J. F., Dobins, Cal.
Whyte, A. C., Ridgefield Park, N. J.
Total, 99.

Students Enrolled, December 18, 1912

5415 Schaetzle, H. J., Univ. of Penn.
5416 Birckhead, L., Univ. of Penn.
5417 Whitaker, J. R., Univ. of Penn.
5418 Chu, V. G., Univ. of Illinois.
5419 Marshall, F. E., Univ. of Illinois.
5420 Buchana, W. B., Univ. of Toronto.
5421 Williams, E. B. Highland Park Coll.
5422 Gailunas, J. P., Iowa State Coll.
5423 Wick, W., Highland Park College.
5424 Spooner, J. W., Highland Pk. Col.
5425 Amo D. C. Highand Park Coll.
5426 Spray L. W. Purdue Univ.
5427 Lickey, H. F., Purdue Univ.
5428 Smith, R. A., Purdue Univ.
5429 Das Gupta, B. N., Purdue Univ.
5430 Wilson, J. H., Purdue Univ.
5431 Hofstetter, R., Purdue Univ.
5432 Smith, H. A., Purdue Univ.
5433 Brady, M. H., Univ. of Missouri.
5434 Kennedy, O. W., Univ. of Penn.
5435 Kroger, W. H., Ohio North. Univ.
5436 Freeman, H.F., Case School of Sci.
5437 Webb, C. B., Case School of Sci.
5438 Kneale, W. E., Case School of Sci.
5439 Hall, L. H., Case School of Sci.
5440 Hoch, E. T., Case School of Sci.
5441 Gizewski, L. B., Case School of Sci.
5442 Woode, N. E., Case School of Sci.
5443 Kaercher, C. M. H., Case School
5444 Beck, C. A., Case School of Sci.
5445 Ober, D. C., Case School of Sci.
5446 Endress, C. H., Case School of Sci.
5447 Sanborn, H. J., Case School of Sci.
5448 Manbeck, P. D., Case School of Sci.
5449 Partridge, E. L., Case School Sci.
5450 Corke, G. R., Univ. of Illinois.
5451 Ferrell, D., Univ. of Illinois.
5452 Jones, R. F., Univ. of Illinois.

5453 Hayes, L. K., Penn. State Coll.
5454 Avera, A. U., Ga. School Tech.
5455 Chang, T. C., Ohio State Univ.
5456 Arnold, S. 3rd. Penn. State Coll.
5457 Hain, R. C., Univ. of Mich.
5458 Strohmer, G. A., Univ. of Mich.
5459 Bixby, R. W., Univ. of Mich.
5460 Glasgow, G. L., Univ. of Mich.
5461 Harvey, H. G., Univ. of Mich.
5462 McCoy, F. G., University of Iowa.
5463 Hatz, L. F., University of Iowa.
5464 Heath, N. P., Univ. of Illinois.
5465 Klinefelter, L. M., Colo. Agri. Coll.
5466 Ratz, E. G., Univ. of Toronto.
5467 Bosshart, H. J., Oakland Poly. Coll.
5468 Olmstead, H. M., Case School Sci.
5469 Havighorst, R. K., Colo Agri. Coll
5470 Henry, J. H., Ohio North. Univ.
5471 Swartz, O. P., Ohio North. Univ.
5472 Hart, R. H., Ohio Northern Univ.
5473 Woo, T. T., Univ. of Illinois.
5474 Harris, M. H., Washington Univ.
5475 Winfree, E. S., Washington Univ.
5476 Cutter, A. L., Washington Univ.
5477 Proetz, B. G., Washington Univ.
5478 Griffith, J. C., Washington Univ.
5479 Blatterman, A. S., Wash. Univ.
5480 Niemoeller, L. H., Wash. Univ.
5481 Baker, P. W., Washington Univ.
5482 Schwarting, H. F., Wash. Univ.
5483 Hadcock, J. P., Toronto, Ont.
5484 Davis, P. L., Jr., Univ. of Cal.
5485 Thompson, W. W., LafayetteColl.
5486 Brackimeid, T. W., Univ. of Tor.
5487 Diver, H. G., Case School of Sci.
5488 Burgess, L. P., Penn. State Coll.
5489 Ralston, E. A., Purdue Univ.
5490 McGowan, C. H., Purdue Univ.
5491 Yates, I. B., Purdue Univ.
5492 Wood, H. S., Throop Poly Inst.
5493 Johnson, C. L., Rensselaer Poly. Inst
5494 Gebhard, P. T., Rensselaer Poly. Institute.
5495 Kaufman, W. S., Ohio State Univ.
5496 Mereness, G. E., Ohio State Univ.
5497 Arndt, R., Ohio State Univ.
5498 Spetka, R. R., Ohio State Univ.
5499 Hanck, E., Ohio State Univ.
5500 Hubbell, J. D., Jr., O. State Univ.
5501 Farmer, T. O., Ohio State Univ.
5502 Frye, R. G., Univ. of Columbus.
5503 Strait, J. M., Ohio State Univ.
5504 Inagaky, T. Y., Ohio State Univ.
5505 Butz, C. H., Univ. of Wisconsin.
5506 Wigle, J. A. H., Univ. of Toronto.
5507 Langford, W. H., Univ. of Mo.
5508 Cook, A. C., Lewis Institute.
5509 Yardley, B., Ohio Northern Univ.
5510 Asbury, L. B., Univ. of Oklahoma.
5511 Asbury, H. T., Univ. of Oklahoma
5512 Stinson, R. W., Univ. of Okla.
5513 Carey, C. E., Univ. of Oklahoma.
5514 Livergood, H., Univ. of Okla.
5515 Evans, R. D., Univ. of Okla.
5516 Hibbard, L. J., Univ. of Okla.
5517 Holland, W. E., Univ. of Okla.
5518 Oakes, M. C., Univ. of Oklahoma.
5519 Ballard, D. A., Univ. of Okla.
5520 Renshaw, D. E., Univ. of Okla.
5521 Gorton, L. H., Univ. of Okla.
5522 Nippes, I. S., Penn. State Coll.
5523 Fultz, M. E., Penn. State Coll.
5524 Rersch, C. M., Penn. State Coll.
5525 Hinckley, S. M., Lewis Institute.
5526 Read, L., Oregon Agri. College.
5527 Johnson, J. W., Ohio North. Univ.
5528 Lieniz, E. M., Lewis Institute.
5529 Van Alst, J. W., Univ. of Penn.
5530 Simons, J., Univ. of Penn.
5531 Wahl, J. H., Univ. of Penn.
5532 Jones, J. A., Univ. of Penn.
5533 Recordon, C. E., Univ. of Penn.
Total 119.

Past Section Meetings

BALTIMORE

The November meeting of the Baltimore Section was held on November 22, in the physical laboratory of the Johns Hopkins University, Chairman J. B. Whitehead presiding. There was a total attendance of 46. This was a telephone meeting, and different divisions of the subject were presented, as follows: "Toll Line Traffic," by Mr. L. M. Clarke, traffic engineer; "Outside Construction," Mr. L. F. Cromwell, district plant engineer; "Telephone Transmission," Mr. H. B. Stabler, equipment engineer; and "Electrolysis," Mr. F. T. Iddings, chief cable tester. All of these speakers were of the Chesapeake and Potomac Telephone Company. A general discussion followed the presentation of the papers.

CHICAGO

A joint meeting of the Chicago Section with the Electrical Section of the Western Society of Engineers was held on November 25, 1912.

Mr. G. C. Seely presided. Mr. R. H. Rice, chairman of the Chicago Section, made an announcement on behalf of the Institute's Constitutional Revision Committee, regarding the work of revising the constitution, which is now in the hands of that committee, and invited an expression of opinion from any of the members present who might desire to make remarks. Chairman Seely then introduced Mr. Ernest Lunn, of the Commonwealth Edison Company, who conducted the meeting. Mr. J. L. Woodbridge, chief engineer of the Electric Storage Battery Company, presented a paper entitled "Some Economical Applications of the Storage Battery." This was followed by a paper on "The Edison Storage Battery," by Mr. H. H. Smith, of the Edison Laboratory.

CLEVELAND

A meeting of the Cleveland Section was held on October 21, when a party of 50, including 25 visitors, visited the Collinwood shops of the Lake Shore and Michigan Southern Railroad and inspected the various departments. At the conclusion of the trip a vote of thanks was passed in appreciation of the courtesy shown by the officials in charge of the shops.

Chairman E. J. Edwards announced the appointment of the following program committee: Mr. J. C. Lincoln, chairman, Mr. William Skiff and Mr. L. H. Baird.

The Section met at the plant of the Peerless Motor Car Company, on November 18, with an attendance of 125 members and visitors.

Papers were presented on the application of electricity to gasoline automobiles, as follows:

"Storage Batteries as Applied to Gasoline Automobiles," by Mr. C. R. Morberg, of the Willard Storage Battery Company, dealing particularly with the starting battery and its characteristics.

"Electric Lighting of Gasoline Automobiles," by Mr. Ralph Beman, of the engineering department of the National Electric Lamp Association, discussing various systems of regulation and giving tests of different types of lamps and reflectors.

"Electric Starters for Gasoline Automobiles," by Mr. E. F. Wackwitz, of the Peerless Motor Car Company, tracing the development of the present low-voltage starting system used on this car.

Short talks were also given on "The Aluminum Cell Used as a Rectifier for Battery Charging," by Professor H. B. Dates, of the Case School of Applied Science, and "The Wagner Battery Charging Apparatus," by Mr. A. B. Shepard, of the Wagner Electric Manufacturing Company.

An inspection and demonstration of the starting apparatus used on the "Peerless" car followed. Luncheon was served by the Peerless Motor Car Company after the meeting.

DETROIT—ANN ARBOR

A meeting of the Detroit-Ann Arbor Section was held on November 23, in Employers Association Hall, Detroit. Mr. J. J. Wolfenden presided, and there was a total attendance of 24. The annual election of officers was held and resulted as follows: Chairman, J. J. Wolfenden; vice-chairman, S. C. Dinsmore; secretary-treasurer, Ray K. Holland; and assistant secretary, G. W. Krause. Mr. Holland then presented a paper describing the new Barton plant of the Eastern Michigan Edison Company, which is under construction near Ann Arbor.

FORT WAYNE

A meeting of the Fort Wayne Section was held at the Fort Wayne Commercial Club on November 14. Chairman A. B. Morrison, Jr., presided, and there was an attendance of 17. Mr. E. A Wagner spoke on the subject of the commercial production of ozone. Mr.

Wagner's presentation included a description of several types of ozonators, the methods of using ozone for purification of water and air, and its use in treating disease of the human body.

ITHACA

A meeting of the Ithaca Section was held in Franklin Hall on October 1. Professor Frederick Bedell presided and there was a total attendance of 51. Mr. L. C. Bowes, chairman of the student division, spoke briefly, explaining to the visiting students the reasons for the formation of the student division and urging them to join actively in the discussions.

The subject of the meeting was "The Power Situation in Chicago," by Professor H. H. Norris. The lecture was illustrated with lantern views and charts. In the discussion which followed Professor V. Karapetoff brought out several arguments in favor of municipal power systems, showing why such systems should be able to supply power at lower rates than can be done by private enterprises.

A meeting of the Section was held in the same place on November 7, when 50 were present. Chairman E. L. Nichols presided. Professor E. E. F. Creighton, staff engineer of the General Electric Company, spoke on the subject of "Electrical Protective Apparatus." Professor Creighton's lecture was based on the paper presented at the Turin meeting of the International Electrical Congress.

LOS ANGELES

The Los Angeles Section held its regular monthly meeting at Blanchard Hall on November 26, 1912. There were present 40 members and visitors. President George A. Damon was in the chair.

The speaker of the evening was Mr. F. W. Harris, who read a paper entitled "Oil Switches and Circuit Breakers." This brought forth discussion by Messrs. E. W. Paul, J. E. Macdonald, C. A. Howell, Ed. Woodbury, R. W. Sorensen, D. D. Morgan and A. W. Nye.

LYNN

A meeting of the Lynn Section was held on November 20 at the G. E. Restaurant. Chairman W. A. Hall presided, and there was a total attendance of 250.

This meeting has been announced as "Microscope Night." The first speaker was Mr. A. L. Ellis, who is in charge of the Lynn standardizing laboratory of the General Electric Company. Mr. Ellis presented a paper on the use of the microscope in the selection and testing of instrument sapphires, diamonds and pivots in instrument practise. Mr. Ellis showed some exceptional photomicrographs arranged especially for his lecture.

The next speaker was Mr. J. M. Darke, chemist and metallurgist of the foundries of the General Electric Company, who exhibited a large number of photomicrographs of steel and iron, showing particularly the changes brought about by processes of heating, annealing and working.

Mr. J. H. H. Burbank then spoke briefly of the possibilities of the microscope for use at home, from the standpoint of amusement. There had been arranged for use on this evening fifty microscopes properly lighted and provided with trained attendants, and each member present was afforded opportunity to study a large number of slides. Professor Thomson explained clearly the use of the instruments.

MEXICO

A meeting of the Mexico Section was held on November 7 at the Salon Bach, in the City of Mexico. Chairman H. S. Foley presided and 35 members and visitors attended. Following the dinner Mr. R. C. Plume spoke on "The Field for Electricity in Heating and Cooking." Mr. Plume had just returned from a visit to the manufacturing plants of the United States, and after sketching briefly the history of the manufacture of electric cooking and heating appliances, told of research work in laboratories which foreshadows great improvements yet to come in the shape of electric fireless cookers and heat storage appliances.

Mr. Plume was followed by Mr. H. W. Beers, whose subject was "Mexican Clay Products for Heating Appliances." Mr. Beers has developed a line of electrical heating and cooking appliances made out of Guadalajara clay, which he described and demonstrated. Messrs. C. V. Allen, S. Altamirano, R. Fingado and others discussed the subject.

The Mexico Section met for the regular monthly session at the Salon Bach on December 5. There were in attendance 61 who, after dining, listened to papers presented by Mr. H. M. Stringfellow, civil engineer of the Mexico Tramway Company, Limited, and Mr. Percy L. Griffith, superintendent of distribution for the Mexican Light and Power Company, Limited. The papers treated of "Interurban Traction Problems," as applied particularly to the electric railways now being built from Mexico City to Puebla and thence to Toluca. The papers were discussed by many of the engineers present.

These roads when completed will be of great scenic beauty and constructed according to the most modern and accepted methods. The road to Puebla will be the highest standard gage electric railway in the world, passing between the famous volcanos of Popocatepetl and Ixtacihuatl at a height of 12,500 ft. (3810 m.) above the level of the sea. The road will have a total length of 180 km. and express trains will travel over it at the rate of 70 km. an hour on the maximum grades and 100 km. an hour on the level stretches. The Toluca branch will traverse the world famous Anahuac Valley and the beautiful Valley of Toluca, having a length of 66 km. The summit between these two valleys will be crossed at a height of 10,200 ft. (3109 m.). The time between the cities of Mexico and Toluca will be 1 hr. 50 min.

MINNESOTA

Forty-five members of the Minnesota Section and ten visitors met on November 11, at McCormick's Cafe, Minneapolis. Chairman A. L. Abbott presided. The meeting was preceded by the usual informal dinner. An amendment to the Section by-laws was passed, providing for standing committees on power transmission, illumination, power plants, telephone and railway engineering.

Mr. Lincoln Nissley, construction engineer for the H. M. Byllesby Company, presented a paper on "Transmission Line Construction," which was discussed by Professor George P. Shepardson, Messrs. R. A. Lundquist and A. Aspnes. Mr. W. C. Beckjord, construction engineer for the St. Paul Gas Light Company, then described the construction of a 1,700-ft. (518-m.) span over the St. Croix River. His description was illustrated with lantern slides. Professor Ryan then gave a short talk on some tests made on an experimental span.

PHILADELPHIA

On December 5 the Philadelphia Section held a joint meeting with the Franklin Institute. Messrs. G. R. Henderson and H. A. Hornor presided, and there was a total attendance of 175. The paper of the evening, "Recent Advances in the Steam Turbine Art," was presented by Mr. H. T. Herr.

A meeting of the Section was held on December 9 at the Engineers' Club, with a total attendance of 123. Chairman H. A. Hornor presided. The subject of "Electrical Methods Used by Fire and Police Departments in Municipalities" was presented by Messrs. John W. Kelly, Washington Devereux and C. W. Pike. A general discussion followed, in which Messrs. C. E. Diehl, of Harrisburg, J. B. Yeakle, of Baltimore, and L. D. Firman took part. This was followed by a demonstration of apparatus by Messrs. Kelly, Devereux and Firman.

PITTSBURGH

The Pittsburgh Section held a social meeting on October 26 in the club rooms of the Union Club in the Frick Building. About 100 persons were present. The entertainment consisted of an amateur minstrel performance arranged by members of the Westinghouse Club, and songs led by Mr. Saul Lavine, during which refreshments were served. The social meeting was voted a great success in arousing interest in the Section and its work.

A meeting of the Section was held on November 12 in the rooms of the Engineers' Society of Western Pennsylvania. Chairman E. L. Farrar presided and there was a total attendance of 130. A paper entitled " Means and Ends of Engineering Education " was presented by Professor F. L. Bishop, dean of the school of engineering of the University of Pittsburgh. The discussion that followed was participated in by Messrs. C. E. Downton, C. R. Dooley, G. M. Eaton, F. D. Newbury, A. H. McIntire, Calderwood, Regenstein, and others.

PITTSFIELD

Professor L. H. Friedburg, of the department of chemistry of the College of the City of New York, addressed the Pittsfield Section, on November 29, on the subject of " Color Photography. "

Professor Friedburg traced the development of the art, and described the various processes, using for illustration the color mixer and numerous lantern slides in the natural colors.

The attendance was 155, including 105 members and 50 visitors, 27 of whom were ladies. Chairman W. C. Smith presided, and Mr. W. S. Moody introduced the speaker.

Preceding the lecture an informal dinner was given, with Professor Friedburg as guest.

PORTLAND, ORE.

The second regular meeting of the 1912-1913 season of the Portland Section was held in the Assembly Hall of the Electric Building, November 19. Chairman H. R. Wakeman presided, and 19 attended the meeting.

A letter was read from Mr. Lardner of San Francisco, concerning the Engineering Congress to be held in 1915. After considerable discussion by several members of the Section, the secretary was instructed to write Mr. Lardner for further information regarding the Congress.

Letters were read from Mr. W. S. Murray, chairman of the Constitutional Revision Committee, and from Mr. P. M. Lincoln, chairman of the Sections Committee, calling the attention of the Section to certain recommendations which had been made.

The matter of making arrangements for permanent headquarters to be used by the various engineering and technical societies in Portland was discussed, but as complete arrangements had not been made, no definite action was taken.

The chairman was authorized by the Section to correspond with other Sections of the Institute on the Pacific Coast and was given complete authority to act for the Section in an effort to secure a vice-president for the Institute from the Pacific Coast.

Following the business session, Mr. W. D. Scott of the Pacific Telephone and Telegraph Company presented a paper on the subject of " Leased Wire Service on the Pacific Coast."

SAN FRANCISCO

The regular monthly meeting of the San Francisco Section was held in the offices of the Pacific Telephone and Telegraph Company on November 29. Professor H. F. Fischer of the University of California read a short paper on the subject of " Artificial Transmission Lines," going into some detail regarding the construction of such lines on the premises of the University of California by students in the electrical engineering course.

Previous to the meeting about fifteen members dined informally at Jules' Restaurant. Chairman H. W. Crozier presided at the meeting, at which there was an attendance of 45, including 5 visitors.

SEATTLE

A meeting of the Seattle Section was held on November 16, in the assembly room of the Chamber of Commerce. Mr. J. D. Ross presided, and there was an attendance of 33 members and 9 visitors. The election of officers for the ensuing year was held, and resulted as follows: Chairman, J. D. Ross; secretary, M. T. Crawford.

Mr. Howard Joslyn, city electrician, talked on the subject of the interior wiring ordinance of the city of Seattle, discussing in detail its various provisions. Mr. Wettrick, chief engineer in the office of the Superintendent of Public Utilities, presented the overhead ordinance of the city of Seattle, with a discussion of its main features. A general discussion followed, by Messrs. Harisberger, Houston, Terrell, Ross, Cooley and others. The Electrical Contractors Association had been invited to this meeting and a number of the members were in attendance.

TOLEDO

On December 6, 30 members of the Toledo Section, with 40 visitors, 20 of whom were ladies, accepted an invitation from Mr. P. L. Van Alstyne to visit the plant of the Toledo Sugar Company. The party was taken through the various departments of the sugar refinery, beginning with the washing and slicing of the raw beets and ending in the store-rooms for the finished product.

VANCOUVER

The regular monthly meeting of the Vancouver Section was held at Moose Hall on November 8, thirty members and visitors being present.

The meeting was called to order by Chairman F. D. Nims, who announced the appointment of the following committees: papers, Messrs. Roberts, Lister and Beebe; co-operation, Messrs. Robinson, Hayward and Anderson; and entertainment, Messrs. Wright, Pease and Kennedy.

Communications were received from the Los Angeles, San Francisco and Portland Sections, in reply to the announcement of the proposed Pacific Coast Convention dates at Vancouver, September 9, 10 and 11, 1913, all approving and promising hearty co-operation.

A letter from Secretary Hutchinson announcing the publication of the revised by-laws was read, as were also those sections of the new by-laws especially affecting the work of the Sections.

The subject of the proposed Pacific Coast Convention was then brought up, and it was decided that the plans for the convention should be discussed at each Section meeting, so that the matter might not be lost sight of by any of the members, and every attempt be made to bring out all possible suggestions towards helping along the work.

A paper was then read by Mr. W. W. Fraser entitled "Notes on Wiring Practise Obtaining in Vancouver." The paper brought out very clearly some of the weak points in the present City by-laws covering electrical work in the city, and a thorough discussion followed.

At the close of the discussion a resolution was adopted:

> "That the papers committee request the city electrician to read before the Section the newly prepared City Electrical By-Laws before they are presented to the City Council for adoption."

WASHINGTON D. C.

The first regular meeting of the Washington Section for the season of 1912-13 was held in the Telephone Building November 12.

Mr. C. B. Mirick presided in the absence of the new chairman, Mr. John H. Finney, the latter having recently been elected to fill the vacancy caused by the resignation of Mr. Earl Wheeler.

Professor Louis D. Bliss, president of the Bliss Electrical School, Takoma Park, Md., addressed the Section, taking for his subject "Modern Illumination."

The speaker began by describing light as a wave motion and comparing it with various other forms of wave motion. He then described the various types of electric lamps, arc, incandescent and mercury vapor, from the earliest types to those in general use at the present time, dwelling more especially on the most modern types, their advantages over the earlier forms, and the various arrangements of lamps of different types for securing the best and most economical lighting effects.

Exhibits of many types of arc and incandescent lamps were shown and there were suspended from the ceiling of the hall several fixtures of different kinds showing the various modern methods of direct, semi-direct and reflected illumination.

A discussion followed, by Messrs. W. N. Smith, C. B. Mirick, B. P. Lamberton, and others.

The meeting was attended by about 140 persons, of whom 80 were visitors.

The regular monthly meeting of the Section was held in the Telephone Building, December 10, 1912, with an attendance totaling 98 persons. Chairman John H. Finney presided.

After a brief executive session the meeting was addressed by Mr. Ralph H. Beach, president of the Federal Storage Battery Car Company, who took as his subject "The Edison Storage Battery and its Application to Car Propulsion."

The speaker described in considerable detail the construction of the Edison battery and then pointed out the several advantages which are claimed for the apparatus, dwelling especially on the durability of the battery and its ability to withstand exceedingly rough usage without injury.

The various applications of the battery to motor and electric car propulsion were then described. It was shown that great things had been accomplished in a comparatively short time in connection with the development of this battery and its application to commercial uses and it was prophesied that this was but the beginning of what may be expected in the future. The address was illustrated with many stereopticon views.

At the close of the meeting a buffet luncheon was served.

Past Branch Meetings

UNIVERSITY OF ARKANSAS

A meeting of the University of Arkansas Branch was held on November 13, when Mr. L. S. Watts read a paper by Mr. S. B. Graham entitled "A Visit to the Transmitter Department of the Western Electric Company." Mr. Graham is an alumnus of the university who is now in the service of the Kellogg Company at New York. His paper described the method used by the Western Electric Company in testing transmitters. A paper on "The Engineer's Field" was then read by Mr. W. D. Dunn.

UNIVERSITY OF CALIFORNIA

The University of California Branch held a regular meeting on the evening of November 12, in the Mechanics Building. Chairman Grunsky presided.

The paper of the evening was presented by Mr. R. C. Griffin, 1913, and dealt with Edison storage batteries. The paper covered the subject thoroughly, and was productive of considerable discussion afterward by most of the members present. These batteries were compared with lead storage batteries as to construction, operation, cost, etc., and their various points of interest brought out.

The next meeting of the Branch was held on November 26. There were sixteen members present, and four persons were elected to membership.

The paper of the evening was presented by Mr. P. L. Davis, Jr., 1913, on the subject of "Telephony." The operation of exchanges in San Francisco was outlined, together with the methods followed and problems encountered. The paper was discussed by Mr. R. G. McCurdy, 1913, and other members present.

CLEMSON AGRICULTURAL COLLEGE

The organization meeting of the Clemson Agricultural College Branch, at Clemson College, S. C., was held on December 4, 1912, with Dr. W. M. Riggs in the chair. The election of officers resulted as follows: Chairman, J. H. Kangeter; secretary, H. J. Bomar; treasurer, E. T. Provost; executive committee, Dr. W. M. Riggs, J. H. Kangeter, D. M. Sloan, H. S. McGee and Professor F. T. Dargan.

A meeting of the Branch was held on December 9, with a total attendance of 24. Some amendments to the constitution of the Branch proposed by the executive committee were accepted. The date for the next meeting was set, January 13, and the following men volunteered to prepare papers for presentation; Messrs. E. T. Provost, D. M. Sloan, M. S. Lawton, H. S. McGee, Dr. W. M. Riggs and Professor W. C. Wagner.

UNIVERSITY OF COLORADO

A meeting of the University of Colorado Branch was held on November 20, when 33 were in attendance. The first speaker was Professor H. S. Evans, who spoke on the advantages of membership in the student Branches of the Institute. The next feature of the program was the reading of a paper entitled "Compilation of Facts of Steam and Electric Load Building in Colorado and Surrounding States," which had been prepared by Mr. John Salberg, of the Denver office of the Westinghouse Electric and Manufacturing Company. Mr. Salberg was unable to be present, and the paper was read by Mr. W. H. Bullock, also of the Westinghouse company. The paper presented carefully prepared historical statistics of electrification of various industries, in comparison with steam power development, in Colorado and the neighboring territory. By means of numerous slides, motor installations for various purposes were shown and explained.

At a meeting of the University of Colorado Branch on December 4 the speaker was Mr. B. C. J. Wheatlake, of the Denver office of the General Electric Company, who presented a paper on "Design of Transformers." Mr. Wheatlake gave the fundamental equations for transformer design, and taking up the standard specifications for transformers, he explained the significance of the items of heating, regulation, floor space, current capacity, voltage, frequency, etc. The speaker described the use of lightning arresters and choke coils for protection, and illustrated the effect of short circuits in transformers by the examples of various accidents. The lecture was illustrated with lantern slides showing various types, methods of cooling, etc.

COLORADO STATE COLLEGE

A meeting of the Colorado State Agricultural College Branch was held on November 7, when Mr. Robert O. Sewell presented a paper descriptive of the arrangement and operation of the plant of the Commonwealth Edison Company at Chicago, Ill. Professor Rankin followed with some personal reminiscences of his work with the same company.

A meeting of the Branch was held on November 21. The speaker was Mr. Mason, an alumnus of the college, now in the employ of the General Electric Company. He described the methods of testing transformers in use by that company, and described the company's apprentice course for technical school graduates.

HIGHLAND PARK COLLEGE

On October 22, 1912, there was held a meeting for the organization of a student Branch of the Institute at Highland Park College, Des Moines, Iowa. The Branch was organized by the election of Mr. Thomas Pellmounter as temporary chairman and Mr. R. R. Chatterton as temporary secretary, and the appointment of the following constitution committee: Dean A. Shane, Mr. J. C. Shutt and Mr. J. W. Spooner.

On October 29 the Branch met and adopted the constitution proposed by the committee, and the following officers for the year were elected: Chairman, J. W. Spooner; vice-chairman, J. C. Shutt; secretary-treasurer, R. R. Chatterton; executive committee, Dean A. Shane, H. E. Johnson and E. R. Witzell.

A meeting of the Branch was held on November 14. A membership committee was appointed, consisting of Messrs. J. F. Farner, E. R. Witzell and D. C. Amo. The executive committee was empowered to draw up a set of by-laws, subject to the approval of the Branch. Two papers recently published in the PROCEEDINGS of the Institute were presented—*Electricity in the Portland Cement Industry*, by F. C. E. Burnett, was abstracted by Mr. Fred Farner, and discussed by Professor Shane, Messrs. Shutt, Pellmounter and Farner; and *The History and Development of Submarine Signaling*, by H. J. W. Fay, was presented in abstract by Mr. C. A. Prussman.

On December 11 the Branch debated the relative merits of the steam engine and the internal combustion engine for electric generation. The steam engine was upheld by Mr. D. J. Stellingworth and Mr. E. E. Gould defended the internal combustion engine. Additional discussion was contributed by Mr. J. F. Farner, Dean A. Shane, Professor Kemp, Professor Knapp, Mr. Stellingworth and Professor Chatterton. The discussion favored steam engines for very large stations and in places where the exhaust steam could be used for heating, etc. The internal combustion engine was favored for small plants.

UNIVERSITY OF IOWA

A meeting of the University of Iowa Branch was held on November 26, when four new members were elected. An illustrated paper on "Electric Signs" was presented by Mr. Lester Lord.

At the meeting of the Branch on December 10, an illustrated paper on "Small Electric Power Plants" was presented by Mr. J. H. Edwards.

UNIVERSITY OF KANSAS

A regular meeting of the University of Kansas Branch was held on November 13. Professor G. C. Shaad spoke on "Depreciation," and Messrs. H. H. Campion and D. K. Crawford of the senior class gave a talk on "The Water Power Development on Vancouver Island."

At the meeting of the Branch on December 4 the speaker was Mr. R. K. McMaster of the Kansas City Electric Light and Power Company. Mr. McMaster's subject was "Distribution," and he used numerous blue prints and charts to illustrate his remarks.

KENTUCKY STATE UNIVERSITY

A meeting of the Kentucky State University Branch was held on December 6, when two papers recently published in the PROCEEDINGS of the Institute were read—*Does it Pay the Average Coal Mine to Purchase Central Station Power?* by Graham Bright, was read by W. C. Armistead, and *Some Features of the Outdoor Electrical Installation*, by F. C. Green, was read by A. H. Colbert.

LAFAYETTE COLLEGE

At the meeting of the Lafayette College Branch on November 19 Mr. F. Maue of the senior class presented a paper on "Electric Dynamometers," in which the history of the development of the various types was given, with descriptions and illustrations of the instruments. Dr. Rood gave a concise summary of the subject and suggested several schemes for improving existing types.

Mr. J. Shimer of the Junior class spoke on "The Stillwell Regulator," outlining the theory and operation of the regulator, and explaining the construction with the aid of illustrations. In the discussion which followed, Dr. Rood pointed out the advantages and disadvantages of the regulator and compared a-c. and d-c. feeder regulation.

At the meeting of the Lafayette College Branch on November 26 Mr. Ellis of the junior class presented a paper on "Excitation of Alternating-Current Generators." The merits and disadvantages of self-excitation were shown and the separately excited system with the Tirrill regulator was discussed in detail, with diagrams, by Mr. Higgins and Professor Rood.

Mr. Laros of the junior class spoke on the three-wire system, showing the economies resulting from a three-wire as compared with a two-wire system.

At the meeting of the Branch on December 3, Mr. Thompson of the junior class spoke on "Train Lighting," with particular reference to electric systems. In the discussion which followed, reference was made to the system in use on the Lehigh Valley Railroad and to the Southern method of using a small turbo-generator on the locomotive for arc headlight and train lighting.

Mr. E. J. Fager of the senior class presented a paper on "Car Heating Systems," with special reference to street railway work. Various types of electric car heaters were described and compared as to heat developed and power consumed.

LEHIGH UNIVERSITY

The Lehigh University Branch held its second monthly meeting of the current season on November 15. In a business meeting presided over by A. E. Olson, 1913, the constitution of the newly-formed Wireless Club was read and ratified by the Branch. Officers were also elected for the Wireless Club, as follows: President, E. R. McLaughlin, 1913; secretary, E. F. Weaver, 1913; treasurer, J. S. Gemmel, 1914.

Professor W. S. Franklin gave the first talk of the evening, on "The Use of Inductance and Condensers in Telephone and Telegraph Work." After performing a number of experiments showing the nature of inductance, Professor Franklin took up the application of the observed phenomena.

By using a combination of inductances and condensers a single line may be operated either as a telephone or as a telegraph system by changing the character of the current used, alternating current carrying telephone messages and direct current operating the telegraph sounders. This method contains a special arrangement whereby the telephone sets may be operated in parallel, in which form telephone operation is most satisfactory.

Professor Franklin showed an experiment in resonance, a phenomenon in which an alternating current of a certain definite frequency may be divided into two currents of greater value. He also showed the whistling arc, the choke-coil lighting arrester and their mechanical analogues.

Mr. Morton Sultzer, 1912, of the electrical department, read a paper on "The Elementary Principles of Wireless Telegraphy." In a short historical sketch the speaker told of the investigations of Maxwell and Hertz in showing the similarity between light waves and electric waves. It remained for Marconi to make practical application of the results of these investigations. In 1906 Mr. Marconi made his first public demonstration in England; and a short time later successful experiments were conducted on vessels at the Kingston Regatta.

Mr. Sultzer showed the elementary nature of wireless as oscillations of a closed condenser circuit with inductance, the oscillations producing waves in leaping across the spark-gap in the circuit. In speaking of the receiving stations the speaker outlined the kinds of detectors used, from the first coherer to the latest vacuum detector.

There was a total attendance of 53 at the meeting.

UNIVERSITY OF MAINE

A meeting of the University of Maine Branch was held on November 15, when the election of officers for 1912-1913 took place, with the following results: Chairman, Howard O. Burgess; vice-chairman, F. C. Goodwin; secretary, J. Larcom Ober; treasurer, L. E. Seekins; executive committee, Professor A. T. Childs, E. R. Page, G. C. Tilley, H. R. Clark and H. O. Burgess.

UNIVERSITY OF MICHIGAN

The University of Michigan Branch met on November 27, when Mr. W. F. Davidson presented a paper of some length on "The Application of Electricity to Iron Mining and Some of the Problems it Presents." A discussion followed in which many of the student members took part.

UNIVERSITY OF MISSOURI

On November 11, there was held a joint meeting of the University of Missouri Branch of the Institute with the student branch of the A. S. M. E., the subject of discussion being "Scientific Management as Applied to Steam-Electric Power Plants." Messrs. Thompson and Jesse took up the mechanical engineering problems involved, and Messrs. Woodson and Langford discussed the electrical and the commercial aspects of the subject. Mr. E. E. Armstrong of the A. I. E. E. Branch presided.

Mr. Thompson told of the various wastes that take place in the furnace and boiler and the methods employed to reduce these to a minimum. He then described methods of purchasing coal and showed the advantages of buying on the B. t. u. basis. Mr. Jesse mentioned the losses that occur in steam engines and turbines, and the ways these can be kept low.

Mr. Woodson showed the losses of power in the electrical system, and using average figures, showed that it is common for not more than 50 to 60 per cent of the power delivered to the generator shaft to reach the customer. Systematic use of recording voltmeters and of totalizing wattmeters is necessary in order to detect where avoidable wastes are going on.

Mr. Langford summarized the work of the manager in keeping his power losses at a minimum, and then emphasized the need of seeing that the labor is efficient, of keeping the plant in first-class repair, of keeping the customers satisfied with good service, and finally of keeping accurate records that will show costs of production, and then, knowing the costs, making such rates as will encourage those lines of business that are likely to prove most profitable.

Fifty-one in all were present at the meeting.

At the regular meeting of the Branch on November 25 the subject discussed was "Applications of Electricity to Mining."

Mr. W. H. Kanzler described some of the difficulties that had been encountered in the early attempts to use electricity in mines, and how these difficulties had been overcome. He then showed the ways in which electricity has been used to operate mining machinery such as drills, and the advantage that has been gained through its use.

Mr. O. F. Taylor compared the different methods of haulage in mines, showing how electricity has been applied with great economies as a result. The problem of supplying power to the electric locomotive was also dealt with.

Mr. H. C. Glick described the arrangements for using electrical power on the hoists, and also showed the extent to which electrical signaling and communication have come into use.

Mr. M. H. Brady told of the use of electricity for ventilating, pumping, and blasting. For blasting it has proved much safer and more reliable and has effected much saving of time. In deep mines it is often necessary to pump the water to the surface in several relays in order to avoid excessive pressures. This means that the pumps must be located at a number of different levels. The problem of furnishing power to these pumps has been greatly simplified by electrical transmission.

At the meeting of the Branch on December 9 the subject of the evening was "The Design of High-Voltage Apparatus."

Mr. L. E. Hildebrand treated the subject in a general way, showing the conditions that have led to the use of high voltages, and explaining what parts of the system have to be designed for high electric pressure.

Mr. H. M. Tickle discussed transmission lines, comparing copper and aluminum for conductors and showing the economy of aluminum on the basis of present market prices. Mr. Tickle then described the different types of line insulators, the methods of spacing conductors, and compared the merits of steel towers and wooden poles.

Mr. F. W. Anderson discussed protective devices, with special reference to lighting arresters.

Mr. E. H. Lewis described the Thury system of constant direct-current transmission, in which the voltages used are nearly as high as those used in a-c. systems. The system was shown to have some decided advantages but also some serious disadvantages.

NEW HAMPSHIRE COLLEGE

The first meeting of the New Hampshire College Branch was held November 25, and took the form of a smoker. The subject, "Electrification of Steam Railroads," was discussed by Messrs. N. D. Paine, G. A. Lang, C. W. Work and Robin Beach, all seniors, who spoke, respectively, on "The New York, New Haven and Hartford Electrification," "The New York Central Electrification," "The Use of Electric Locomotives in Tunnels and Terminals," and "Possibilities of Future Electrification." The meeting was then thrown open for questions and further discussion by faculty members and students.

At the meeting of the Branch held December 9, Mr. Robin Beach, a senior, spoke on "Steam Turbines and Turbo-Generators." Mr. Beach described the general principles on which turbines operate, and from this passed to the theory of the impulse type, the reaction type and the impulse-reaction type. He then described the several standard turbines and turbo-generators by means of lantern slides.

NORTH CAROLINA A. & M. COLLEGE

The meeting of the North Carolina Agricultural and Mechanical College Branch on November 18 was devoted to a discussion of the papers presented at the meeting of the Institute in New York on October 11, 1912. *The Use of Reactance in Transformers*, by W. S. Moody, was read in abstract by Mr. T. R. Parrish, and *The Effect of Temperature upon the Hysteresis Loss in Sheet Steel*, by Malcolm MacLaren, was abstracted by Mr. G. T. Rowland A general discussion followed.

OHIO NORTHERN UNIVERSITY

At the meeting of the Ohio Northern University Branch on November 19, Mr. W. F. Franks read a paper on

" Determination of Power Efficiency of Rotating Machinery."

Mr. G. M. Hafer then spoke on " Interior Wiring," which he illustrated with numerous slides. In his discussion he described the different methods of interior wiring and showed the correct and incorrect method of placing fuses, etc.

The last meeting of the Branch for 1912 was held December 11, with Chairman F. M. Billhimer presiding. *The Effect of Temperature upon the Hysteresis Loss in Sheet Steel, Some Features of the Outdoor Installation*, and *Use of Reactance in Transformers*—recent Institute papers—were presented by F. D. Henry, L. P. Wood and A. V. Belding, respectively.

OHIO STATE UNIVERSITY

A meeting of the Ohio State University Branch was held on November 13, when a committee was appointed to arrange a program of short talks by members describing their practical experiences.

On November 21 a program of short talks was presented by the following speakers: Mr. W. T. Stubbins, " Electric Railways;" Mr. T. F. Kuechle, " Elevators;" Mr H. T. Bryan, " Contracting;" Mr. E. Hauck, " Elevator Signal System in the Columbus Savings and Trust Building;" Mr. A. M. Lloyd, " Carbon and Its Uses."

A meeting was held on December 4, when the project of holding an electrical show was discussed, and a committee was appointed to look into the matter.

UNIVERSITY OF OKLAHOMA

The University of Oklahoma Branch of the Institute was organized at a meeting held on November 27, when the following officers were elected: Chairman, David E. Renshaw; vice-chairman, Weaver E. Holland; secretary, Leo H Gorton,and treasurer, Lloyd J. Hibbard. The chairman appointed the following executive committee: Messrs. H. V. Bozell, DeAuburn Ballard, and Charles E. Cary.

UNIVERSITY OF OREGON

At the meeting of the University of Oregon Branch on November 12, Professor R. H. Dearborn read a paper on " Some Developments in Electric Railway Engineering." The relative advantages of alternating and direct current were discussed. Raising the trolley voltage from 600 to 1200, Professor Dearborn said, made possible the spacing of substations twice as far apart. There is a possibility that the d-c. trolley voltage will go to 2400 or higher. The 1200-volt trolley construction of the Oregon Electric Railway was described. The arrangement of the side-entrance and double-decked cars, recently introduced in the East, was shown by a number of sketches.

Mr. W. T. Neill related some of his experiences on construction work during the past summer. He described the methods used in unloading and installing a large frequency changer set without the use of a crane.

OREGON AGRICULTURAL COLLEGE

The first meeting of 1912-13 of the Oregon Agricultural College Branch was held on October 7. Mr. Bevan of the physics department spoke on " Volcanos in the Philippines."

At the meeting on October 31, the annual election of officers was held, resulting as follows: Chairman, Lance Read; secretary-treasurer, Charles Oakes; executive committee, Professor Hillebrand, L. H. Kistler, George Milner, Professor Shepard and Dr. W. Weniger.

At the meeting on November 14 Mr. Blair spoke on the subject, " Our Celestial Neighbors." The lecture was illustrated with lantern slides of the moon and Mars. One hundred members and visitors were present.

A meeting of the Branch was held on December 5, when Professor Hillebrand lectured on " The Duties of a Public Service Corporation." Plans were discussed for the annual engineering show, which is to be held in January.

PURDUE UNIVERSITY

The meeting of the Purdue Branch of October 22 was addressed by Professor C. R. Moore. The subject of his discourse was " A Direct-Reading Power Meter " for the development of which he has been largely responsible. Professor Moore briefly reviewed the various methods of measuring power in use at the present time and in the past, pointing out the essential features and inherent difficulties of each. Following this he described an apparatus for measuring power directly at one reading instead of measuring torque and speed separately as in most methods and obtaining the power as a product of these two.

The apparatus works on the following principle. Two alternators of the same sine wave voltage, if connected in series and operated at the same speed, give a resultant sine wave voltage proportional to the speed at which they operate and to the sine of the angle of phase difference between them, or, if the angle of phase difference is small, proportional to the angle of displacement itself.

As constructed, the apparatus much resembles the well known transmission type of dynamometer which uses a helical spring to measure the torque. It consists essentially of two small revolving field type alternating-current generators mounted on a single base and having their shafts connected by a helical spring of a size and stiffness suitable to the torque to be transmitted. The field windings of the two generators are connected in series and in opposition through a suitable voltmeter so that at zero load the resultant voltage is zero. The power transmitted through the shaft and helical spring is proportional to the product of the speed and torque and the torque, in turn, is proportional to the twist in the interconnecting spring and hence to the angle of phase displacement of the two generators. Since the voltmeter indicates the resultant voltage, which, as pointed out above, is proportional to the product of speed and angular displacement if the latter is small, it is obvious that the voltmeter reading will be proportional to the power transmitted. To make the apparatus direct-reading it is only necessary to calibrate the voltmeter in connection with the whole device by transmitting through the mechanism known amounts of power. One of the alternator armatures is provided with a device whereby its angular position with respect to the other may be adjusted to give zero reading on the voltmeter. This arrangement makes it possible to make a power measurement without having a zero error to account for.

Considerable difficulty was experienced in earlier attempts to produce such an apparatus as described, because of the variation of the wave forms of the two generators from sine waves. It is obvious that the resultant voltage will not be a sine wave and not proportional to the sine of the angle of displacement unless the component voltages have that form. It was not until the oscillograph disclosed this decrepancy in the earlier models that the difficulty was discovered and remedied in the apparatus which was exhibited and operated during the evening.

Animated discussion followed the close of the paper.

About one hundred and fifty people were in attendance.

The meeting of the Purdue Branch on November 12 was devoted to the subject of " Railway Signaling." Professor H. O. Garman after giving a brief history of railway signaling told about the various kinds of plants now in use. Lantern slides of the plants discussed, including the mechanical plant at Hammond, Ind., which is the largest of its kind in the United States, were shown. Professor Garman's talk was from the standpoint of the operating engineer.

Mr. Burr S. Swezey, 1913, then explained in detail the interlocking system now used. He also described the different kinds of plants now in general use and the advantages of each.

Mr. G. W. Weston, 1913, continued by explaining the staff system. This system is used in places where the traffic is very heavy, as across long bridges and in mountainous districts where the cost of double tracking would be almost prohibitive. This is not an up-to-date system but it is absolutely safe.

Mr. J. C. Potter was the next speaker. He explained the electrical control of the automatic block system, and by means of diagrams showed just how the system works. How this system gives warnings of broken rails was shown, and the great importance of the fact, especially since very heavy trains are now run at such great speed.

Alternating current is now coming into general use as power for operating the automatic signals, because of the increasing demand for these signals on electric lines and the necessity for a power which is independent of earth currents. Several recent installations were discussed, particularly that at the new Chicago and Northwestern Railroad depot at Chicago. Mr. Potter concluded by stating how the present systems are inadequate for perfect protection, and pointing out the lines along which study and experimentation are now being carried on.

At a meeting of the Purdue Branch held on December 3, the subject presented was "Motor Control Apparatus." Mr. H. E. McIvor began by enumerating the general requirements of elevator control apparatus and stated the advantages of certain kinds. Direct-current motors are used almost exclusively with the series field extra strong. The speed is controlled by the shunt field rheostat. The controller is equipped with several special devices, viz., overload relay, dynamic brake, solenoid switches, and current relays. The overload relay is connected to the car controller and may be reset without the operator leaving the car. The mechanical brake is always set by a spring and released by the current. Dynamic braking is effected by letting the motor run as a generator with its circuit closed by a resistance, so that the energy is dissipated as heat in the circuit.

Professor L. D. Rowell continued with a discussion of various types of motor control apparatus. The same motor may be used for a half dozen widely differing kinds of service using different methods of control. There are two large divisions of controllers, manual and automatic. Each of these divisions may be subdivided into three classes according to their use, *i. e.*, for starting duty, for regulating duty, and for controlling duty.

There are several types of automatic controllers, those in which the time period is controlled by mechanical means, as by a dash pot, those in which the starting period is controlled by the counter electromotive force of the motor, and those in which the current is delivered to the machine just as fast as the motor can take it. This last type is called the series relay or current limiting type of controller, and is used extensively for very heavy service.

The counter e.m.f. type has an advantage in passenger elevator work, that the steps by which the motor is accelerated depend on the speed of the motor and can therefore be more readily adjusted for smooth acceleration.

RENSSELAER POLYTECHNIC INSTITUTE

The first meeting for the year 1912-1913 of the Rensselaer Polytechnic Institute Branch was held in the Sage Laboratory on November 13. A paper on "Automatic Telephone Systems" was read by Mr. Wynant J. Williams. The automatic telephone apparatus recently purchased by the Rensselaer Institute was exhibited at this meeting

The discussion of the paper was followed by the usual smoker.

At the meeting of the Branch on December 11, Mr. W. H. Reichard, R. P. I. 1905, of the Federal Signal Company, Albany, N. Y., spoke on "Electricity in Railway Signaling." Mr. Reichard has been for several years engaged in developing the electrical apparatus used by this company in its signal systems, and his description of the difficulties met with in this field of applied electricity and the methods used to overcome them was very instructive.

STANFORD UNIVERSITY

A meeting of the Stanford University Branch was held on November 14. A motion was passed empowering the chairman to appoint an assistant librarian, with the understanding that the appointee should be a candidate for the office of librarian at the next regular election.

A paper entitled "Calculation of Transmission Lines" was presented by Professor J. C. Clark, who gave a very practical talk on the problems connected with the design of transmission lines. The paper was followed by a general discussion.

UNIVERSITY OF VIRGINIA

A meeting of the University of Virginia Branch was held on November 13, when Mr. Gano Dunn, past-president of the Institute, spoke on the subject "The Educational Value of Engineering Studies." Mr. Dunn said that the subjects given in engineering courses are gradually taking the place of the classics, and pointed out the fact that the ability to adapt oneself to circumstances is as much a necessary qualification of the good engineer as is the knowledge of the work in hand.

STATE COLLEGE OF WASHINGTON

A meeting of the State College of Washington Branch was held on November 19, when Mr. Arlie Redpath of the senior electrical class presented a paper entitled "Edison and his Battery," giving a brief outline of the life of Thomas A. Edison and a very complete description of his storage battery.

At the meeting of the Branch on November 26, a paper on "The General Electric Test Course" was presented by Mr. Howard Melvin, 1910. Mr. Melvin has recently returned from his work with the General Electric Company and has accepted the position of instructor in electrical engineering in the college.

A meeting was held on December 3, when Mr. F. W. Thwaites of the senior mechanical class presented a paper on "Mechanical Stokers," paying particular attention to the types that have been more recently put upon the market.

WORCESTER POLYTECHNIC INSTITUTE

A meeting of the Worcester Polytechnic Institute Branch was held on November 22. The subject of the meeting was summer experiences.

The speakers were all members of the senior class in the electrical engineering department at the Institute, and spoke on the work in which they had been engaged, as follows:

Mr. Franzen, "Apprenticeship Course of the Sprague Electric Company."

Mr. Gilson, "Mining, Idaho Springs, Colorado."

Mr. Graham, "Telephone Installation and Maintenance."

Mr. Rockwell, "Apprenticeship Course of the Canadian Westinghouse Company."

Mr. Stripp, "Putting Theory into Practise."

YALE UNIVERSITY

The meeting of the Yale Branch held in Mason Laboratory on November 14 was the first of the year at which students were the speakers. The subject of the meeting was "The National Code." Mr. R. P. Hart, 1913S, read a paper on "The Origin and Object of the Underwriters' Rules." His paper was illustrated by stereopticon views. The next paper, by Mr. D. P. Anderson, dealt with the requirements for house wiring. He showed various kinds of fixtures, fuses, switches, etc., and illustrated his talk with experiments. A paper by Mr. W. G. Smith treated the subject of the manufacture of wire and requirements for its insulation.

An interesting discussion followed, in which Professor C. F. Scott, Mr. Reeks of New York, Chief Fancher of the New Haven Fire Department, and other engineers joined.

The total attendance was 86.

" Turbo-Generator Design and Practise " was the title of an illustrated lecture by Mr. T. W. Reed at a meeting of the Yale Branch held on December 3. Mr. Reed is with the General Electric Company in the turbine department. His talk covered the development of the steam turbine from its earliest form to the present types of large capacities. The subject of rotary air compressors was dealt with briefly.

The discussion after the lecture brought out, among other things, many operating characteristics of turbines and comparison in cost between turbo-generators and reciprocating engines with generators.

The total attendance, New Haven engineers and students, was seventy.

Personal

Mr. H. T. Plumb, formerly a professor of electrical engineering at Purdue University, has been appointed local engineer of the General Electric Company at Salt Lake City, Utah.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

L'Action Electrique du Soleil. By A. Nodon. Paris, 1910. (Purchase.)

Alternating-Current Machinery. By William Esty. Chicago, American School of Correspondence, 1912. (Gift of publishers.) Price $3.00.

Professor Esty's work is of course intended for private study in a correspondence course, and is thus designed for a reader having only rudimentary knowledge of mathematics. The reviewer, who is a fair representative of that type, finds no statements which he cannot understand.
W. P. C.

Bare Aluminum Cables. By H. M. Hobart. London, 1910. (Purchase.)

Die Chemie der Cellulose. By Carl G. Schwalbe. Berlin, 1911. (Purchase.)

Congreso Cientifico (1° Pan Americano) Ciencias Naturales, Antropologicas y Etnologicas. Tomo III. (Volumen XVII.) Santiago de Chile, 1912. (Gift of Congreso Cientifico. 1° Pan Americano.)

Economics in Railway Operation. By F. E. Wynne. East Pittsburgh, Westinghouse Electric & Manufacturing Co. 1912. (Exchange.)

Electrical Patents (U. S. Patent Office). 368 copies. (Gift of Mr. Bissing.)

Electrical Photometry and Illumination. By Herman Bohle. Philadelphia, J. B. Lippincott Company, 1912. (Gift of publishers.)

The author is a member of the faculty of South African College, Cape Town, and the work is an amplified form of lectures delivered in 1911. It summarizes in a most convenient volume modern practice in illumination. There is a seven page bibliography. W. P. C.

Elektrische und magnestische Messungen und Messinstrumente. By H. S. Hallo and H. W. Land. Berlin, 1906. (Purchase.)

Der Elektromotor im Kleingewerbe und Handwerk. By Ludwig Hammel. Frankfurt A.M., 1910. (Purchase.)

Die Europäischen Fernsprechgebühtartife. By Erwin Günther. Jena, 1910. (Purchase.)

France. Bureau de Longitudes. Annuaire pour l'An 1913. Paris, Gauthier-Villars, 1912. (Gift of Publishers.)

Fuhrer durch das Patentwesen aller Länder der Erde. Berlin, 1911. (Purchase.)

Die gebräuchlichsten Damfturbinen-Systeme für Land-und Schiffszwecke nach Konstruktion und Wirkungsweise. By Max Dietrich. Rostock i.M., 1906. (Purchase.)

Handbuch der Elektrizität und des Magnetismus. Band II, lieferung I. By L. Graetz, Leipzig, 1912. (Purchase.)

Handbuch der Schaltungsschemata für elektrische Starkstromanlagen. Band I-II. Berlin, 1904-05. (Purchase.)

Institution of Engineers and Shipbuilders in Scotland. Transactions, vol. LV. Glasgow, 1912. (Gift.)

International Catalogue of Scientific Literature. Annual Issue 10th. B—Mechanics. London, 1912. (Gift of E. D. Adams Fund.)

Jahrbuch der Radioaktivität und Elektronik. Band 5-8. Leipzig, 1908, 1910, 1912. (Purchase.)

Der Kautschuk. Eine Kolloidchemische Monographie. By Rudolf Ditmar. Berlin, 1912. (Purchase.)

Law Relating to Engineering. By L. W. J. Costello. London, 1911. (Purchase.)

Maschinen und Apparate der Starkstromtechnik ihre Wirkungsweise und Konstruktion. By G. W. Meyer. Leipzig, 1912. (Purchase.)

Messungen an Maschinen und Motoren für Ein-und Mehrphasen Wechselströme. By Fritz Hoppe. Leipzig, 1910. (Purchase).

Messungen an Maschinen und Motoren für Gleichstrom. By Fritz Hoppe. Leipzig, 1909. (Purchase.)

Mesure de l'Equilibre des Circuits Téléphoniques. (Extrait des Annales des Postes, Télégraphes et Téléphones Sept., 1912.) By M. B. Gáti. Paris, N.d. (Gift of author.)

Monographien über angewandte Elektrochemie. Vols 5, 8-19, 21-37. Halle a.S., 1903-1911. (Purchase.)

National Board of Fire Underwriters. List of Electrical Fittings. Oct., 1912. (Gift of National Board of Fire Underwriters.)

National Civic Federation. Regulation of stock and bond issues. Preliminary page proof.

——Regulation of Intercorporate Relations. Preliminary page proof.

——Franchises. Preliminary page proof. (Gift of National Civic Federation.)

New Jersey. Board of Railroad Commissioners. Annual Report 1st, 1907. Paterson, 1908.

——Board of Public Utility Commissioners. Annual Report 1st, 1910. Trenton, 1911. (Gift of New Jersey Railroad Commissioners.)

New Orleans. Sewerage and Water Board. 25th Semi-annual report, 1912. New Orleans, 1912. (Gift of New Orleans Sewerage and Water Board.)

New York State Public Service Commission for the First District. Annual Report. 1910, vol. IV; 1911, vol. I. Albany, 1911-12. (Exchange.)

North East Coast Institution of Engineers and Shipbuilders. Transactions, vol. XXVIII. Newcastle-upon-Tyne, 1912. (Gift.)

Photographic Optics and Colour Photography. By G. L. Johnson. London, 1909. (Purchase.)

Zur Physiologie und Hygiene der Luftfahrt. By N. Zuntz. (Heft 3. Luftfahrt und Wissenschaft. von J. Sticker.) Berlin, 1912. (Purchase.)

Power. By C. E. Lucke. New York, 1911. (Purchase.)

Prinzip und Wirkungsweise der technischen Messinstrumente für Wechselstrom. By Fritz Hoppe. Leipzig, 1910. (Purchase.)

Prinzip und Wirkungsweise der Wattmeter und Elektrizitatäzähler für Gleich und Wechselstrom. By Alex. Königswerther. Leipzig, 1912. (Purchase.)

Production Electrique de L'Ozone et applications a L'Industrie L'Hygiène la Thérapeutique. By Etienne Douzal. Paris, 1909. (Purchase.)

The Railway Library and Statistics, 1911. By Slason Thompson. Chicago, 1912. (Gift of author.)

Reducing the Toll of the Sea. The Submarine Signal. By W. Packard. (Reprinted from *New England Magazine*, Sept., 1912.) N.p. n.d. (Donor unknown.)

Report on Legal and Franchise Matters Charter Amendments to the Board of Supervisors, City of San Francisco. By B. J. Arnold. Preliminary Report No. 13, pt. 1, submitted Nov. 5, 1912. San Francisco, 1912. (Gift of B. J. Arnold.)

——Report on Relief of Traffic Congestion on Lower Market Street. By B. J. Arnold. Preliminary Report No. 6, submitted Oct. 30, 1912. San Francisco, 1912. (Gift of B. J. Arnold.)

Rules of Resuscitation from Electric Shock. New York, 1912. (Gift of National Electric Light Association.)

Southwestern Electrical and Gas Association. Proceedings of Annual Convention. 4th, 5th. Dallas, 1908, 1909. (Gift of Association.)

A Study of Trolley Light Freight Service and Philadelphia Markets in their Bearing on the Cost of Farm Produce. By C. L. King, Philadelphia, 1912. (Gift of Philadelphia Dept. of Public Works.)

Theoretische und experimentelle Untersuchungen über künstliche Hochspannungs-Kabel. By R. David. Berlin, 1910. (Purchase.)

Die Theorie der Wechselströme. By Ernst Orlich. Leipzig, 1912. (Purchase.)

Der Torsionsindikator. I. Die elektrischen methoden zur Verdrehungsmessung. By Paul Nettmann. Berlin, 1912. (Purchase.)

Die Vektoranalysis und ihre Anwendung in der Theoretischen Physik. Teil I-II. By W. v. Ignatowsky. Leipzig, 1909, 1910. (Purchase.)

Wallingford (Conn.) Board of Electrical Commissioners of the Borough Electric Works. Report year ending July 31, 1912. N.p., 1912. (Gift of Alfred L. Pierce.)

Wireless Telegraphy and Telephony. By W. J. White. Ed. 2. New York, The Macmillan Co., 1912. (Gift of publishers.) Price $1.00.

A book for the general reader, not for the engineer. Would be useful in a public library.

W. P. C.

TRADE CATALOGUES

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Crocker-Wheeler Co., Ampere, N. J.—Bull. No. 150—Coupled and belt types of alternating current generators. Sept., 1912.

——Bull. No. 158—Adjustable speed motors. Sept., 1912.

Delta-Star Electric Co., Chicago, Ill.—Bull. No. 1—S. E. C. High tension fuses. Sept., 1912.

De Witt Wire Cloth Co., New York, N. Y.—Catalogue No. 80. 1909. 148 pp.

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——Revised list of wire ropes and wire cords. 1911. 11 pp.

Estey Wire Works Co., New York, N. Y.—Catalogue and price list (wire cloth) No. 20. 63 pp.

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General Electric Co., Schenectady, N. Y.—Bull. No. A 4036.—Direct current exciter panels. Oct., 1912. 8 pp.

——Bull. A 4037—Isolated and small plant switchboards. Oct., 1912. 14 pp.

——Bull A 4039—Direct current motor-starting and speed regulating rheostats and panels. Oct., 1912. 35 pp.

——Bull. A 4040—Contractors for industrial service. Oct., 1912. 10 pp.

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UNITED ENGINEERING SOCIETY

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(Term expires July 31, 1913.)

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- EDWIN J. HOUSTON, 1893-4-5.
- LOUIS DUNCAN, 1895-6-7.
- FRANCIS BACON CROCKER, 1897-8.
- A. E. KENNELLY, 1898-1900.
- CARL HERING, 1900-1.
- CHARLES P. STEINMETZ, 1901-2.
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- LOUIS A. FERGUSON, 1908-09.
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- DUGALD C. JACKSON, 1910-11.
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*Deceased.

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Revised to January 1, 1913.

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Term expires July 31, 1916.

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Revised to January 1, 1913.

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Revised to January 1, 1913.

Name and when Organized.	Chairman.	Secretary.
Atlanta...........Jan. 19, '04	A. M. Schoen.	H. M. Keys, Southern Bell Tel. & Tel. Co., Atlanta, Ga.
Baltimore.........Dec. 16, '04	J. B. Whitehead.	L. M. Potts, Industrial Building, Baltimore, Md.
Boston............Feb. 13, '03	Fred. P. Valentine.	Leavitt L. Edgar, 39 Boylston St., Boston, Mass.
Chicago..................1893	Ralph H. Rice.	E. W. Allen, 1028 Monadnock Building, Chicago, Ill.
Cleveland.........Sept. 27, '07	E. J. Edwards.	R. B. Chillas, Jr., National Carbon Co., Cleveland, Ohio.
Detroit-Ann Arbor.Jan. 13, '11	J. J Woolfenden.	Ray K. Holland, Cornwall Building, Ann Arbor, Mich.
Fort Wayne.......Aug. 14, '08	A. B. Morrison.	P. H. Haselton, Fort Wayne Electric Works, Ft. Wayne, Ind.
Indianapolis-Lafayette.Jan. 12, '12	O. S. More.	Charles A. Tripp, 710 Majestic Building, Indianapolis, Ind.
Ithaca............Oct. 15, '02	E. L. Nichols.	George S. Macomber, Cornell University, Ithaca, N. Y.
Los Angeles.......May 19, '08	G. A. Damon.	E. R. Northmore, Los Angeles Gas and Electric Company, Los Angeles, Cal.
Lynn.............Aug. 22, '11	W. A. Hall.	E. R. Berry, General Electric Co., Lynn, Mass.
Madison..........Jan. 8, '09	E. H. Kifer.	F. A. Kartak, Univ. of Wisconsin, Madison, Wis.
Mexico...........Dec. 13, '07	H. S. Foley.	James Carson, Mexican Light and Power Company, Mexico City, Mexico.
Milwaukee........Feb. 11, '10	T. E. Barnum.	L. F. Reinhard, Mechanical Appliance Co., Milwaukee, Wis
Minnesota........Apr. 7, '02	A. L. Abbott.	Fred A. Otto, St. Paul Gas Light Co., St. Paul, Minn.
Philadelphia.......Feb. 18, '03	H. A. Hornor.	H. F. Sanville, 1326 Chestnut St., Philadelphia, Pa.
Pittsburgh........Oct. 13, '02	E. L. Farrar,	M. C. Turpin, Department of Publicity, W. E. and M. Company, Pittsburgh, Pa.
Pittsfield..........Mar. 25, '04	W. C. Smith.	W. W. Lewis, General Electric Company, Pittsfield, Mass.
Portland, Ore......May 18, '09	H. R. Wakeman.	G. P. Nock, Pacific Tel. and Tel. Co., Portland, Ore.
San Francisco.....Dec. 23, '04	H. W. Crozier.	A. G. Jones, 819 Rialto Building, San Francisco, Cal.
Schenectady.......Jan. 26, '03	John B. Taylor.	J. A. Dewhurst, Gen. Elec. Co., Schenectady, N. Y.
Seattle............Jan. 19, '04	J. D. Ross.	M. T. Crawford, 608 Electric Bldg., Seattle, Wash.
St. Louis..........Jan. 14, '03	Joseph A. Osborn.	F. J. Bullivant, 6400 Plymouth Avenue, St. Louis, Mo.
Toledo............June 3, '07	George E. Kirk.	Max Neuber, Care of Cohen, Friedlander & Martin, Toledo, O.
Toronto...........Sept. 30, '03	F. A. Gaby.	H. T. Case, Continental Life Bldg., Toronto, Ont.
Urbana...........Nov. 25, '02	A. M. Buck.	F. G. Willson, University of Illinois, Urbana, Ill.
Vancouver........Aug. 22, '11	F. D. Nims.	E. M. Breed, Allis-Chalmers-Bullock, Ltd., Vancouver, B. C.
Washington, D. C..Apr. 9, '03	John H. Finney.	H. C. Eddy, Interstate Commerce Commission, Washington, D. C.

Total, 28.

LIST OF BRANCHES.

Revised to January 1, 1913.

Name and when Organized.	Chairman.	Secretary.
Agricultural and Mechanical College of Texas......Nov. 12, '09	S. E. Bowler.	E. S. Lammers, Jr. College Station, Texas.
Arkansas, Univ. of......Mar. 25, '04	W. B. Stelzner.	G. W. Watkins, Room 25, Buchanan Hall, Fayetteville, Ark.
Armour Institute........Feb. 26, '04	W. Fryberg.	R. L. Walsh, Armour Inst. Tech., Chicago, Ill.
Bucknell University ....May 17, '10	E. M. Richards.	Robert L. Rooke, Bucknell University, Lewisburg, Pa.
California Univ. of......Feb. 9, '12	Charles Grunsky.	C. I. Kephart, University of California, Berkeley, Cal.
Cincinnati. Univ. of......Apr. 10, '08		
Clemson Agricultural College...............Nov. 8, '12	J. H. Kangeter.	H. J. Bomar, Clemson College, S. C.
Colorado State Agricultural College ....Feb. 11, '10	Robert O. Sewell.	R. K. Havighorst, Colorado State Agricultural College, Fort Collins, Colo
Colorado, Univ. of.......Dec. 16, '04	Harry McKinney.	Seizo Uyeda, 1075 12th St., Boulder, Colo.
Highland Park College..Oct. 11, '12	J. W. Spooner.	Ralph R. Chatterton, Highland Park College, Des Moines, Iowa
Iowa State College......Apr. 15, '03	H.C.Bartholomew	F. A. Robbins, Iowa State College, Ames, Iowa.
Iowa, Univ. of..........May 18, '09	L. F. Hatz.	A. H. Ford. University of Iowa, Iowa City, Ia.
Kansas State Agr. Col....Jan. 10, '08	B. F. Hillebrandt.	W. C. Lane, Kansas State Agric. Col., Manhattan, Kan.
Kansas, Univ. of.........Mar. 18, '08	S. S. Schooley.	A. J. Fecht, Univ. of Kansas, Lawrence, Kan.
Kentucky, State Univ. of Oct. 14, '10	R. B. Pogue.	W. M. Lane, 216 Rose Street, Lexington, Ky.
Lafayette College........Apr. 5, '12	F. W. Maue.	W. O. Hay, Jr. Lafayette College, Easton, Pa.
Lehigh University........Oct. 15, '02	W. J. Dugan.	E. F. Weaver, Lehigh University, S. Bethelhem, Pa.
Lewis Institute..........Nov. 8, '07	Ralph Kilner.	A. H. Fensholt, Lewis Institute, Chicago, Ill.
Maine, Univ. of.........Dec. 26, '06	Howard O.Burgess	J. Larcom Ober, S. A. E. House, Orono, Maine.
Michigan, Univ. of......Mar. 25, '04	Ward F. Davidson	Edward A. Roeser. Univ. of Michigan, Ann Arbor, Mich.
Missouri, Univ. of.......Jan. 10, '03	H. B. Shaw.	E. W. Kellogg, 9 Engineering Building, Columbia, Mo.
Montana State Col......May 21, '07	Lawrence Wylie.	J. A. Thaler, Montana State College, Bozeman, Mont

LIST OF BRANCHES.—Continued.

Name and when Organized.	Chairman.	Secretary.
Nebraska, Univ. of......Apr. 10, '08	Geo. H. Morse.	V. L. Hollister, Station A, Lincoln, Nebraska.
New Hampshire Col.....Feb. 19, '09	Robin Beach.	Clayton W. Work, New Hampshire College, Durham, N.H.
North Carolina Col. of Agr. and Mech. Arts...Feb. 11, '10	S. B. Sykes.	J. W. Johnson, N. C. College of A. and M. Arts, West Raleigh, N. C.
Ohio Northern Univ.....Feb. 9, '12	F. M. Billhimer.	J. E. Wineland, Ohio Northern University, Ada, Ohio.
Ohio State Univ.........Dec. 20, '02	R. E. Kinkead.	T. O. Farmer, Ohio State Univ., Columbus, Ohio.
Oklahoma Agricultural and Mech. Coll.......Oct. 13, '11	A. P. Little,	J. W. Harvey, 416 Hester Street, Stillwater, Okla.
Oklahoma, Univ. of.....Oct. 11, '12	David E.Renshaw	Leo H. Gorton, 526 UniversityBoulevard,Norman,Okla.
Oregon Agr. Col........Mar. 24, '08	Lance Read.	Charles E. Oakes, Oregon Agric. Col., Corvallis, Ore.
Oregon, Univ. of........Nov. 11, '10	R. H. Dearborn.	C. R. Reid, Univ. of Oregon, Eugene, Oregon.
Penn State College......Dec. 20, '02	K. P. Fuhrman.	I. S. Nippes, Pennsylvania State College, State College, Pa.
Purdue Univ...........Jan. 26, '03	C. F. Harding.	A. N. Topping, Purdue University, Lafayette, Ind.
Rensselaer Poly. Inst..Nov. 12, '09	E. D. N. Schulte.	W. J. Williams, Rensselaer Poly. Institute, Troy, N. Y.
Rose Polytechnic Inst...Nov. 10, '11	S. Irwin Stocking.	Joseph E. O'Connell, 457 N. 8th Street, Terre Haute, Ind.
Stanford Univ..........Dec. 13, '07	Gustav Wade.	Walter J. Dodge, Stanford University, California.
Syracuse Univ..........Feb. 24, '05	W. P. Graham.	R. A. Porter, Syracuse University, Syracuse, N. Y.
Texas, Univ. of.........Feb. 14, '08	J. A. Correll.	N. H. Brown, University of Texas, Austin, Tex.
Throop Poly. Inst.......Oct. 14, '10	Ray Gerhart.	R. W. Parkinson, Throop Poly. Institute, Pasadena, Cal.
Vermont, Univ. of.......Nov. 11, '10	Walter L. Upson.	O. Krupp, 65 North Bend St., Burlington, Vt.
Virginia, Univ. of........Feb. 9, '12	Walter S.Rodman	Henry Woodman Clark, A. X. P. House, University, Virginia.
Wash., State Coll. of....Dec. 13, '07	M. K. Akers.	H. V. Carpenter, State Col. of Wash., Pullman, Wash.
Washington Univ.......Feb. 26, '04	C. E. Wright.	A. S. Blatterman, Washington University, St. Louis, Mo
Worcester Poly. Inst...Mar. 25, '04	Harry B. Lindsay.	George I. Gilchrest, Worcester Poly. Inst., Worcester, Mass.
Yale University.........Oct. 13, '11	E. C. Willard, Jr.	M. R. Wibberley, 361 Elm Street, New Haven, Conn.

Total 45.

PROCEEDINGS
OF THE
American Institute
OF
Electrical Engineers.

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THE EDITING COMMITTEE

GEORGE R. METCALFE, Editor

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Vol. XXXII **February, 1913** No. 2

A. I. E. E. Regular February Meeting Omitted

As announced in the report of the Directors' meeting of January 10, it was voted to omit the regular New York meeting of the Institute for February 14, in order to concentrate every effort upon the Midwinter Convention, February 26—28. The regular monthly meeting of the Board of Directors will be held on February 14, 1913.

A. I. E. E. Midwinter Convention

Announcement

The New York Midwinter Convention of February 1913 is to be held under the auspices of the Standards Committee, which is preparing data for a revision of the Standardization Rules. Recent investigation has shown that the present Standardization Rules of the American Institute of Electrical Engineers are inadequate to meet the most recent practise and tendencies. It was therefore considered desirable to present proposed modifications to the electrical engineering fraternity for comment and suggestions before adopting them in the rules.

The list of papers to be presented at the convention is given herewith. The first two papers on the list, which are presented by the sub-committee on Revision of Rules, and the sub-committee on Rating, were printed for advance distribution as well as in this issue of the PROCEEDINGS, and it is particularly desired by the Standards Committee that written discussion should be furnished on these two papers, with a view to being printed in advance of the convention.

It is also desired to obtain, at the earliest possible date, written contributions to the discussion of any or all of the papers. Such contributions to the discussion as are received at the Secretary's office before February 10 will be printed in advance and will be available for distribution before the meeting on request. It is urged that all such discussion may present only constructive criticism so as to promote the objects for which the convention is held. These objects cannot be furthered by the expression of opinions other than those based on very careful consideration of the propositions involved. In order to be printed in advance, contributions to the discussion should be devoid of diagrams or illustrations.

It is proposed that in order to economize time for discussion, the papers already printed in the February PROCEEDINGS should be read by title or abstract only at the convention. Much importance is attached to the written contributions to the discussion as it is hoped that these will contain valuable suggestions and opinions of a wide circle of members and other interested parties who may have found it impracticable or inexpedient to contribute formal papers.

All of the papers for this convention are printed in this issue, except program Nos. 6, 28 and 45.

PROGRAM

The papers are classified in the order of their presentation, under four groups, as follows:

Group I. Heating, Heat Measurements, Rating by Heat.

Group II. Methods of Determining Losses in Apparatus.

Group III. Methods of Testing Apparatus for Performance.

Group IV. Miscellaneous Subjects Relating to Rating.

Wednesday, February 26

10: 30 A.M.

The Convention will open with a brief introductory address by the chairman of the Standards Committee, and will be followed by two sub-committee papers, as follows:

1. *Temperature and Electrical Insulation*, by C. P. Steinmetz and B. G. Lamme. (Sub-committee on Revision of Rules.)
2. *Method of Rating Electrical Apparatus*, by W. L. Merrill, W. H. Powell and Charles Robbins. (Sub-committee on Rating.)

The discussion on the sub-committee papers will be followed by the presentation by abstract of Group I papers, and their discussion.

This discussion will be continued in the afternoon.

8: 00 P.M.

Conclusion of discussion on Group I papers.

Thursday, February 27

10: 00 A.M.

Opening address by Mr. H. G. Stott upon the use of the "myriawatt" and "myriawatt-hour" in connection with rating; to be followed by presentation by abstract and discussion of papers in Group II.

This discussion will be continued in the afternoon.

8: 00 P.M.

Conclusion of discussion on Group II papers.

Friday, February 28

10: 00 A.M.

Presentation by abstract and discussion of papers in Group III.

2: 00 P.M.

Presentation by abstract and discussion of papers in Group IV.

9: 00 P.M.

Reception and dance at Hotel Astor.

Papers to be Presented at A. I. E. E. Midwinter Convention

February 26-28, 1913

1. *Temperature and Electrical Insulation*, by C. P. Steinmetz and B. G. Lamme. (Sub-committee on Revision of Rules.)
2. *Method of Rating Electrical Apparatus*, by W. L. Merrill, W. H. Powell and Charles Robbins. (Sub-committee on Rating.)

Group I. Heating, Heat Measurements, Rating by Heat

(a) MOVING MACHINERY

3. *Notes on Internal Heating of Stator Coils*, by R. B. Williamson.
4. *Measurement of Temperature on Rotating Electric Machines*, by L. W. Chubb, E. I. Chute, and O. W. A. Oetting.
5. *Method of Determining Temperature of A-C. Generators and Motors and Room Temperature*, by H. G. Reist and T. S. Eden.
6. *Thermocouples and Resistance Coils for the Determination of Local Temperatures in Electrical Machines*, by J. A. Capp and L. T. Robinson.

(b) TRANSFORMERS

7. *Methods of Determining Temperature of Transformers and of Cooling Medium*, by S. E. Johannesen and G. W. Wade.
8. *Methods of Measuring Temperature of Transformers*, by C. Fortescue and W. M. McConahey.
9. *Correction of Transformer Temperature for Variation of Room Temperature, Taking into Account Both Copper and Iron Losses*, by C. Fortescue.

(c) TEMPERATURE CORRECTION

10. *The Temperature Rise of Stationary Induction Apparatus*, by J. J. Frank and W. O. Dwyer.
11. *Effect of Room Temperature on Temperature Rise of Motors and Generators*, by M. W. Day and R. A. Beekman.
12. *Effect of Air Temperature, Barometric Pressure and Humidity on the Temperature Rise of Electrical Apparatus*, by C. E. Skinner, L. W. Chubb and Phillips Thomas.
13. *A Laboratory Investigation of Temperature Rise as a Function of Atmospheric Conditions*, by C. B. Blanchard and C. T. Anderson.
14. *Laws of Heat Transmission in Electrical Machinery*, by Irving Langmuir.

(d) CABLE HEATING

15. *Current Rating of Electric Cables*, by R. W. Atkinson and H. W. Fisher.
16. *The Heating of Cables Carrying Current*, by S. Dushman.

Group II. Methods of Determining Losses in Apparatus

(a) INDUCTION MOTORS

17. *Induction Motor Load Losses*, by H. G. Reist and A. E. Averrett.
18. *Stray Losses in Induction Motors*, by A. M. Dudley.
19. *Notes on Induction Motor Losses*, by R. W. Davis.

(b) TRANSFORMERS

20. *Losses in Transformers*, by W. W. Lewis.
21. *Stray Losses in Transformers*, by C. Fortescue and W. M. McConahey.

(c) GENERATORS, A-C. AND D-C.

22. *Determination of Load Loss Correction Factors for Rotating Electric Machines*, by E. M. Olin and S. L. Henderson.
23. *Load Losses of Alternating-Current Generators*, by W. J. Foster and E. Knowlton.
24. *Notes on Stray Losses in Synchronous Machines*, by F. K. Brainard.
25. *Stray Losses in Direct Commutating Machines*, by H. F. T. Erben and H. S. Page.

(d) ERRORS OF TESTS

26. *The Determination of Stray Losses from Input-Output Tests*, by L. T. *Robinson.*
27. *Sources of Error in Efficiency Determination of Rotating Electric Apparatus*, by Elmer I. Chute and William Bradshaw.

(e) BRUSH LOSSES

28. *Commutator and Brush Losses*, by W. N. Motter.
29. *Brush Friction and Contact Losses*, by H. F. T. Erben and A. H. Freeman.
30. *Methods of Determining Brush Losses Due to Contact and Friction*, by H. R. Edgecomb and W. A. Dick.
31. *Commutation and Brush Losses*, by C. E. Wilson.

Group III. Methods of Testing Apparatus for Performance

(a) GENERATORS AND INDUCTION MOTORS

32. *Comparison of Methods of Loading Large A-C. and D-C. Generators and Synchronous Converters for Factory Temperature Test*, by F. D. Newbury.
33. *Comparison of Methods of Making Load Tests on A-C. Generators and on Induction Motors*, by E. F. Collins and W. E. Holcombe.
34. *Notes on Method of Making Load Tests on Large Induction Motors*, by A. M. Dudley.

(b) TRANSFORMERS

35. *Load Tests on Transformers*, by J. J. K. Madden.
36. *Sources of Error in Transformer Tests*, by W. M. McConahey and C. Fortescue.

Group IV. Miscellaneous Subjects Relating to Rating

(a) OIL SWITCHES

37. *Rating of Oil Circuit Breakers with Reference to Rupturing Capacity*, by G. A. Burnham.

(b) SPARK GAP

38. *The Sphere Spark Gap*, by S. W. Farnsworth and C. Fortescue.
39. *The Calibration of the Sphere Gap Voltmeter*, by L. W. Chubb and C. Fortescue.

(c) WAVE FORM

40. *Potential Waves of A-C. Generators*, by W. J. Foster.
41. *Wave Form Distortions and Their Effects on Electrical Apparatus*, by P.M. Lincoln.
42. *A Proposed Wave Shape Standard*, by Cassius M. Davis.

(d) REGULATION

43. *The Experimental Determination of the Regulation of Alternators*, by A. B. Field.
44. *Regulation of Definite Pole Alternators*, by S. H. Mortensen.
45. *Generator and Prime Mover Capacities*, by David B. Rushmore and E. A. Lof.

Entertainment

It has been thought best to have this a working convention, and therefore no special entertainment features have been provided.

The following companies have, however, very courteously offered to open their stations for inspection by any members presenting a badge during the hours of 2 to 5 p.m. on each day of the convention.

New York Edison Co., Waterside Station,
38th to 40th St. & East River.
Substation, 45 West 26th Street.

Interborough Rapid Transit Co., 59th St. Station,
59th Street and North River.
Sub-station, 264 W. 96th Street.

American Telephone and Telegraph Co., and the New York Telephone Co.,
Central Station, 15 Dey St.

The convention will close with a reception and dance to be held at the Hotel Astor, February 28, at 9:00 p.m. Arrangements for attending the reception can be made at the registration office.

NOTE. The New York Entertainment Committee will maintain an information bureau at the registration office, during the convention.

Registration

Each member and guest, upon registration, will receive a badge bearing his or her name, to be worn during the convention for the purpose of identification. The registration headquarters will be in the lobby of the Engineering Societies Building, and the members are earnestly requested to register themselves and their guests promptly on arrival.

Hotel Arrangements

As ample hotel accommodations are available in the neighborhood of Institute headquarters, no special hotel arrangements have been made. Members will therefore make their own hotel reservations.

Transportation

No special transportation rates are available. Members should, therefore, consult their local ticket agents regarding routes and rates. Parlor and sleeping car accommodations should be engaged in advance.

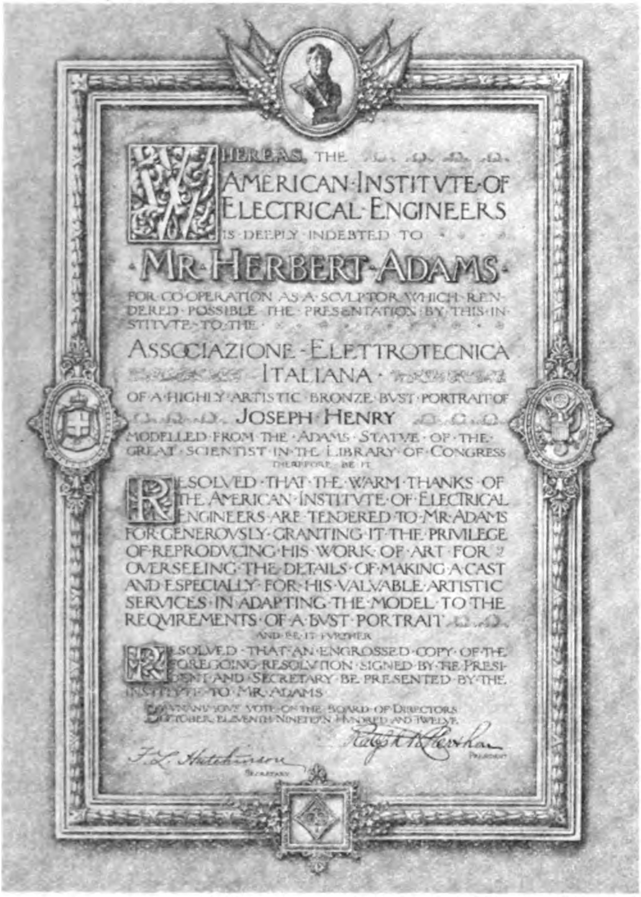
Secretary Hutchinson Convalescent

Since the issue of the January PROCEEDINGS, Secretary Hutchinson has left the hospital and is now regaining his normal condition. After spending a few days with his sisters at Elizabeth, N. J., he has gone to Atlantic City to recuperate, by advice of his physician. He hopes to resume his duties at the next meeting of the Board of Directors, on February 14.

Presentation to Mr. Herbert Adams of Engrossed Resolutions of Thanks

The day before Christmas, Mr. Herbert Adams was the guest of the Institute at a luncheon given in his honor at the Engineers' Club in New York under the auspices of the Italian Memorial Committee. The occasion was the presentation to Mr. Adams of an engrossed copy of the special resolutions of thanks passed by unanimous vote of the Board of Directors in October.

The accompanying cut shows the resolutions as engrossed.



WHEREAS, THE
AMERICAN·INSTITVTE·OF
ELECTRICAL·ENGINEERS
IS·DEEPLY·INDEBTED·TO
·MR·HERBERT·ADAMS·
FOR·CO-OPERATION·AS·A·SCVLPTOR·WHICH·RENDERED·POSSIBLE·THE·PRESENTATION·BY·THIS·INSTITVTE·TO·THE
ASSOCIAZIONE·ELETTROTECNICA
ITALIANA·
OF·A·HIGHLY·ARTISTIC·BRONZE·BVST·PORTRAIT·OF
JOSEPH·HENRY
MODELLED·FROM·THE·ADAMS·STATVE·OF·THE·GREAT·SCIENTIST·IN·THE·LIBRARY·OF·CONGRESS
THEREFORE·BE·IT

RESOLVED·THAT·THE·WARM·THANKS·OF THE·AMERICAN·INSTITVTE·OF·ELECTRICAL ENGINEERS·ARE·TENDERED·TO·MR·ADAMS FOR·GENEROVSLY·GRANTING·IT·THE·PRIVILEGE OF·REPRODVCING·HIS·WORK·OF·ART·FOR OVERSEEING·THE·DETAILS·OF·MAKING·A·CAST AND·ESPECIALLY·FOR·HIS·VALVABLE·ARTISTIC SERVICES·IN·ADAPTING·THE·MODEL·TO·THE REQVIREMENTS·OF·A·BVST·PORTRAIT
AND·BE·IT·FVRTHER

RESOLVED·THAT·AN·ENGROSSED·COPY·OF·THE FOREGOING·RESOLVTION·SIGNED·BY·THE·PRESIDENT·AND·SECRETARY·BE·PRESENTED·BY·THE INSTITVTE·TO·MR·ADAMS

BY·VNANIMOVS·VOTE·OF·THE·BOARD·OF·DIRECTORS OCTOBER·ELEVENTH·NINETEEN·HVNDRED·AND·TWELVE.

Ralph D. Mershon
PRESIDENT

F. L. Hutchinson
SECRETARY

The actual presentation was made by Mr. C. O. Mailloux, chairman of the committee, who, in graceful words, emphasized the sincerity of the Institute's appreciation of all Mr. Adams had done. President Mershon then added to the good feeling which prevailed by making a few happy remarks.

In acknowledgment, Mr. Adams confessed to being deeply moved by this additional proof of good will, and referred to his relations with the Institute as having been a source of great pleasure, the memory of which would always remain with him.

A. I. E. E. Lectures on Radioactivity

A series of lectures on radioactivity will be presented to the Institute by Professor Edwin P. Adams of the Palmer Physical Laboratory, Princeton University, on Tuesday evenings, March 18 and 25 and April 1 and 8, at 8:15 p.m. in the auditorium of the Engineering Building, 33 West 39th Street, New York.

These lectures will offer an unusual opportunity for engineers to obtain an insight into the nature of the phenomena which have been discovered in this most fascinating field of research. The discovery of radioactive substances and the study of their properties constitute probably the most important support of modern accepted theories of the nature of electricity and matter.

Professor Adams has consented in these lectures to present a general survey of the history and important results of research in radioactivity and the bearing of these results on modern electrical theory. They will aim to respond directly to the increasing demand from electrical engineers for a simple and comprehensive description of the phenomena of radioactivity. They will assume that the hearer has no present knowledge of the subject.

The conduct of the course of lectures is under the direction of the Electrophysics Committee of the Institute. The lectures will be open to the membership of the Institute. The members of the American Institute of Mining Engineers, the American Society of Mechanical Engineers, the American Society of Civil Engineers, the Electrochemical Society and the Illuminating Engineering Society are also invited to attend the lectures.

Directors' Meeting January 10, 1913

The regular monthly meeting of the Board of Directors of the American Institute of Electrical Engineers was held in New York on Friday, January 10, 1913.

The Directors present were: Ralph D. Mershon, President, New York; Gano Dunn, Past-President, New York; David B. Rushmore, and Charles W. Stone, Schenectady, N. Y., W. G. Carlton, New York, A. W. Berresford, Milwaukee, Wis., W. S. Murray, New Haven, Conn., Severn D. Sprong, Brooklyn, N. Y., Vice-Presidents; H. H. Barnes, Jr., W. S. Rugg, Charles E. Scribner, and William McClellan, New York, F. S. Hunting, Ft. Wayne, Ind., J. Franklin Stevens, Philadelphia, Pa., Comfort A. Adams, Cambridge, Mass., Managers; George A. Hamilton, Treasurer; Ralph W. Pope, Acting Secretary.

The action of the Executive Committee in appointing Mr. Ralph W. Pope Acting Secretary during the illness of Secretary F. L. Hutchinson, was approved.

The Secretary announced the following committee appointments made by the President: Committee on Use of Electricity in Mines: George R. Wood, chairman, W. E. Moore, H. M. Warren, H. H. Clark, J. T. Jennings, W. A. Thomas, K. A. Pauly, C. T. Henderson, C. W. Goodale, L. S. Noble, William Kelly. Special Committee on Organization and Work of Technical Committees: H. G. Stott, chairman, H. W. Buck, H. S. Putnam, C. A. Adams, P. M. Lincoln. Representatives of the Institute upon the Library Board of the United Engineering Society: Samuel Sheldon, Frederick Bedell, Dugald C. Jackson, Malcolm MacLaren, F. L. Hutchinson. Executive Committee of Committee on Organization of International Electrical Congress: Charles F. Scott, first vice-president; the appointment of Mr.Scott followed the resignation from the committee of Mr. W. D. Weaver.

The Standards Committee reported

certain resolutions adopted at its meeting held on December 13, 1912, in conjunction with a special committee of the American Society of Mechanical Engineers, recommending the use of the term "myriawatt" as the unit of thermal or mechanical power in connection with boilers, producers, turbines and engines, and the discontinuation of the use of the term "boiler horse power." The committee further recommended the publication of the resolutions in the PROCEEDINGS and the technical press.

The Board approved the Standards Committee's recommendations both as to the use of the term "myriawatt" and the publication of the resolutions.

Chairman Rugg of the Meetings and Papers Committee announced that arrangements had been made for a series of four lectures to be delivered before the Institute by Professor E. P. Adams, of the Palmer Physical Laboratory, Princeton University, on Tuesday evening of each of the last two weeks in March and the first two weeks in April, under the auspices of the Electrophysics Committee.

The Board voted to give publicity to the lectures through the PROCEEDINGS and technical press, and to extend to the members of allied engineering societies, through their respective secretaries, an invitation to attend the lectures.

The Meetings and Papers Committee made an informal report regarding arrangements for the midwinter convention, which indicated that a large number of papers would be presented, and that the Standards Committee was engaged in perfecting the program.

Upon the recommendation of the Standards Committee the Secretary was instructed to communicate with the secretaries of other engineering societies, inviting their members to attend the sessions of the midwinter convention and to take part in the discussions.

Upon the recommendation of the Meetings and Papers Committee the Board voted to omit the February New York meeting, in order that the committee could concentrate its efforts on the midwinter convention.

The action of the Finance Committee in approving monthly bills amounting to $10,297.07 was ratified.

A communication was read from Professor W. F. Durand, chairman of the Conference Committee on the International Engineering Congress, San Francisco, 1915, stating that the local committee of the congress was being organized, and that it was desirable for the Institute to appoint its representatives on the committee at the earliest possible date. The President was authorized to appoint three representatives on the local committee.

Notice having been given to the Board by the secretary of the Board of Trustees of the United Engineering Society of the expiration, in the latter part of January, of the term of Mr. W. S. Rugg as a representative of the Institute upon the Board of Trustees, Mr. Charles E. Scribner was unanimously appointed to succeed Mr. Rugg upon this board, for the term of three years ending on the fourth Thursday in January, 1916, as provided in the by-laws of the United Engineering Society.

The Secretary announced that in accordance with Section 21 of the Institute by-laws President Mershon would automatically become a member of the John Fritz Medal Board of Award on the third Friday of January, vice Mr. Louis A. Ferguson, whose term expires on that date.

Upon the recommendation of the Board of Examiners 67 Associates were elected and eighty-one students were ordered enrolled.

The following Associates were transferred to the grade of Member: Charles R. Underhill, New Haven, Conn., Charles F. Conn, San Francisco, Cal. The following Members were transferred to the grade of Fellow: Alexander E. Keith, Chicago, Ill., Henry A. Lardner, San Francisco, Cal.

THE FORUM

Dedicated to the Discussion of Institute Affairs

CONSTITUTION OF THE INSTITUTE

To the membership of the A. I. E. E.:

I should like to be permitted to point out an error in the argument presented in the December issue of the PROCEEDINGS, bearing on the desirability of another revision of the Constitution of the Institute. I only ask such a privilege for the reason that I have been a member of several committees on the revision of the constitution, and was the chairman of the committee which prepared the constitution adopted in 1901, to which reference was made in the December issue.

The fallacy referred to is the seeming assumption that the present constitution is, and the previous constitutions were, mere " quilt " work, that the function of previous committees has been merely to patch up and not rewrite the instrument to be superseded. This misunderstanding is probably due to the practise of calling a new constitution an amendment to that superseded, in order to conform to the phraseology of the constitutional clause whereby authority is given to make changes, which clause, however, does not imply that quite a new document may not be substituted for the existing one.

For example, in preparing the constitution of 1901, a careful study was made of the organic law of all American and British professional bodies of prominence, which codes, in fact, largely served as models for the new constitution; and it was assumed that there was no restriction placed upon preparing a document bearing, if thought necessary, little resemblance to that to be " amended." I am not aware that any other understanding prevailed at the " revision " of 1907, and consequently, instead of the present constitution being a " quilt-work," with patches dating from 1885, 1892, 1894, 1896 and 1901, it will probably be found that it was written to represent as nearly as possible all of the then-existing conditions of which account should be taken.

If, therefore, the present constitution is now in any sense obsolete, it has become so only through changes of conditions which have occurred during the last few years.

The other argument offered for the desirability of a new constitution, namely, that the conduct of the Institute is handicapped by limitations imposed by the present instrument, is one involving a principle on which there may be considerable honest difference of opinion. One thing seems unquestionable—that the membership at large alone should decree any changes affecting in any degree the fundamental principles according to which the Institute should be conducted. The constitution is the organic law which should strictly limit the body to the purposes for which it is organized, and the function of the officers provided under it is solely to administer this law as they find it, or, if discovered to be deficient, to propose to the membership remediable changes. If anything, the constitution of 1907 was too lax in several particulars, as, for example, in not sufficiently guarding admission to the higher grade of membership, and in not limiting the manner in which the Board of Directors may commit the Institute on questions of industrial or other matters of policy having little or nothing to do with " the advancement of the theory and practise of electrical engineering and of the allied arts and sciences, and the maintenance of a high professional standing among its members." Of course, by amendment, this constitutional limit to the activities of the Institute may be formally extended to industrial matters, but to do so would in time lead without doubt to the formation of a new body limited in scope to that of a professional organization for the nurture of the electrical sciences and arts regardless of the relations of these to a constantly shifting industrial situation.

Perhaps there may exist other reasons than those here considered which render desirable the rewriting of the constitution. It appears to the writer, however, to be the part of wisdom to adhere in any revision, and particularly in one undertaken at the present time, to the idea of a strictly guarded constitutional basis for all activities of the society, with the least possible allowance of latitude in the administration of this organic law. Should it be found upon investigation in detail that under present conditions a serious handicap is encountered through the existing method of amending the constitution, this could, to a large extent at least, be overcome by shortening the period in which a proposed amendment could be acted upon, that period being approached as nearly as can be to the time that at present is required to make a new by-law by action of the Board of Directors.

Though aside from the main object of this communication, reference might here be made to the desirability, on the grounds of professional propriety, of the elimination in any future revision of the constitution, of such industrial corporation appendages as "General Counsel" and "Law Committee." The Institute is little more than a corporation by courtesy, and in fact was incorporated only to acquire a legal status as a property owner. Such appendages of industrial and commercial corporations engaged in the fierce battle for dollars, serve, in the best sense, for the protection of their rights or, in the worst sense, for infringement on the rights of others; on the other hand, the Institute is subject to no menace against its constitutional purposes, and does not, of course, desire to profit from legal technicality in its conduct. On rare occasions, when it may be actually desirable to obtain legal advice, this could be secured in the same manner as when a professional man feels he should consult a lawyer. If the former more dignified and appropriate name of "Council" were substituted for "Board of Directors," the professional impropriety of the present legal adjuncts to the government of the Institute would stand out still more clearly.

W. D. Weaver

Charlottesville, Va.,
December 30, 1912

Engineering and Efficiency*

By H. G. Stott

Engineering has been defined by Tredgold as "the art of directing the great sources of power in nature for the use and convenience of man."

Efficiency may be defined as the art of obtaining the maximum output from the minimum input.

With these two definitions in mind, we will proceed to analyze the relations between the two, keeping in touch as much as possible with the work of our own times.

If we take our own branch of engineering, we will find that in its brief career of thirty years it has already been subdivided into at least twenty distinct divisions.

Some of these branches of engineering do not make any claim to exist for the purpose of developing higher efficiency in the strictest sense of the word, but do exist for convenience, and owing to their convenience they have now become necessities.

Take telegraphy, for example; it is difficult (if we follow Tredgold's definition of engineering) to see any connection between telegraphy and efficiency, as we have defined it; and the same argument applies to telephony and many other branches of general engineering, such as sanitation, surveying and military engineering, etc.

We have all become so accustomed to

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*Presented before the Schenectady Section, A. I. E. E., December 4, 1912.

the use of the word "efficient" that instinctively we feel that, whilst the above illustrations may be true, yet *per se* these various branches of engineering may be carried on in a more or less efficient manner. This instinctive feeling is a recognition of the fact that our original definition of engineering was lacking in that it ignored the economic factor which now plays such an important part in the engineer's work.

The moment we recognize the economic factor, we immediately see that telegraphy and telephony are most highly efficient, as they save enormous amounts of time, and it is probably no exaggeration to say that the average business man's efficiency has been improved at least 10 per cent by their use, which virtually means that a man now can accomplish as much in ten years as he formerly did in eleven, when the telephone and telegraph did not exist. In the same way, the work of the sanitary engineer has resulted in opening up parts of the world which were formerly so deadly in character as to be almost impossible for the white races. Notable instances of this are the work of our sanitary engineers in Cuba and the Isthmus of Panama, which were formerly scourged by yellow fever and malaria; but now, thanks to the engineer's work, they are almost as healthy as our northern states.

There is another instance where the economic factor enters again, for the efficiency of the whole world is increased a little when we open up new territory for habitation by the human race.

The company with which the speaker is connected has been engaged in important work, which has also resulted in greatly increased efficiency through the use of sound engineering principles; and as many novel problems were encountered, a brief sketch of the more important may prove interesting.

The existing New York subway system was designed to carry a maximum of 400,000 passengers per day; but the growth of the city was so rapid that some means had to be taken to relieve the intolerable congestion of the system. As a result of careful study, it was decided to lengthen the station platforms so as to accommodate six-car local trains and ten-car expresses in place of the original five- and eight-car trains. This, in itself, was no small problem, as traffic had to be maintained whilst all this construction work was going on; but fortunately this difficult feat in engineering was accomplished without accident.

Ten-car trains were run experimentally and it soon developed that numerous new problems were to be solved by the car equipment department. Cars which formerly behaved in a decorous manner developed alarming characteristics of the broncho when coupled in tens, and refused to stay hitched together when accelerating or retarding. Further study developed the fact that the standard form of draft gear was no longer suited to handle multiple-unit trains of the weight and power used in the subway, and that instead of having the usual lost motion between cars, it was essential that there be no lost motion. This meant the design of pneumatic draft gear of a novel type, which successfully met the requirement of no lost motion.

During the period of retardation the ten-car trains had also broken apart and a careful examination of the facts showed that the brakes were not being applied synchronously on all the cars, due to the time lag of the air in the train line. Electricity was brought into play at this point and a new type of electrically operated air valve was developed and substituted for the old air line, with highly satisfactory results.

The introduction of pneumatically operated center side doors gave rise to many difficult problems in the redesign of the original cars, but all these were successfully overcome.

In order to reduce the length of the stops at the station, a new system of signalling to the motorman was developed; all the doors were equipped with a simple and sturdy type of circuit switch and all these switches were connected in series through a bell in the motorman's cab. This accomplishes a twofold purpose; first, giving the starting signal to the motorman the moment the doors are closed, and second, making sure that the train will not be started until *all* the doors are closed.

It also became imperative to shorten the interval between trains and this was accomplished by a re-arrangement of the signal system such as to permit an interval of less than three minutes, as originally operated.

In the motive power department we were confronted with a number of problems which called for solution in order to provide power for the operation of the additional cars and trains.

The low-tension feeder system was largely reinforced, and at points midway between substations circuit breakers were installed between each of the four contact rails and a common bus, so as to parallel the third rails and thus get the benefit of the conductivity of all the feeders to reduce the momentary drop during the brief periods of acceleration of the ten-car trains, when each one takes about 2600 kw. These tie-in circuit breakers are operated by air pressure and are controlled from the adjacent substations; being interlocked with feeder circuit breakers, each track can be isolated from the substation switchboard at a moment's notice, thus giving great flexibility to the low-tension system.

The substations had been designed so as to accomodate six or eight 1500-kw. synchronous converters, and as more power was required the problem was either how to get more converters in, or else how to install larger machines in the same space occupied by the 1500-kw. units. The first alternative was possible in some of the substations, but not in others, so the manufacturer was called in and requested to design as large a converter as the space would permit. This resulted in the development of a 3000-kw. unit and later, of an interpole converter capable of carrying a load of 4500 kw. for three hours and 10,000 kw. for one minute.

To illustrate the progress of the art, we can now obtain a unit which will occupy the same floor space as the original 1500-kw. machine, but with a steady rating of over 6000 kw. and 12,000-kw. rating for thirty seconds.

In the power plant it also became necessary to get additional capacity and several alternatives were considered, amongst them being the installation of the regular high-pressure turbine as a prime mover. If this course had been adopted, the existing high-grade engine-driven units would have been disposed of at the price of scrap, but fortunately an alternative in the shape of a low-pressure turbine was available, and this type of unit was installed in connection with five of the engine-driven units. The installation of these low-pressure machines resulted in some very important economies; first, they gave a new lease of life to their partners, the reciprocating units; second, they gave an increase of 100 per cent in the maximum capacity of the plant; third, an increase of 146 per cent in the economic capacity, and lastly, but not least, an improvement of 25 per cent in economy of the plant.

The result of all these improvements in the system was that the subway had the interval between trains cut down from three minutes to one minute and forty-eight seconds, or an improvement of 40 per cent; and the daily capacity was increased from 400,000 passengers to over 1,000,000 at the same time. This is surely an illustration of the relationship between engineering and efficiency.

However, we should not feel too much pride in our achievements, as a moment's consideration of the losses going on will speedily restore us to a feeling of proper humility.

The five large power plants in New York City consume approximately 3500 tons of coal per day and of this coal, costing approximately $11,000, 60 per cent, or $6,600 per day, is lost in the condenser. In effect, we are deliberately dumping $2,370,000 per annum into the sea.

Again, of the total fuel burned under our boilers, only about an average of 15 per cent is available for useful work, so that out of our $4,000,000 worth of fuel we waste $3,400,000 per annum. These large power plants are probably at least three times as efficient as the average factory plant, so that instead of having an average thermal efficiency of 15 per cent, the average of the entire country is in all probability not to exceed 6 per cent.

It will never be possible to recover all the heat in our coal, but there is a wide enough margin between 6 per cent and 100 per cent to encourage our engineers in the hope that they may achieve fame and wealth by discovering some new means of conserving our supply of fuel.

In the meantime, the problem is largely an economic one, for we seem to reach a state in the art in about every decade where the saving of fuel, due to the installation of more efficient apparatus, more than offsets the destruction of capital caused by deliberately scrapping *good* machinery for the sake of more *efficient* machinery.

Four years ago, in a vainglorious moment, I attempted to improve upon Tredgold's definition of engineering, and now I feel that I must, in closing, make another attempt at a better definition, which will include efficiency:

Engineering—the art of obtaining the maximum return from the minimum expenditure, of capital and labor, or of the forces and materials of nature.

A. I. E. E. Meeting in New York, January 10, 1913

The two hundred and seventy-ninth meeting of the Institute was held in the auditorium of the Engineering Societies Building, New York, Friday evening, January 10, 1913.

President Ralph D. Mershon called the meeting to order at 8:15 o'clock, and then turned the remainder of the technical session over to Mr. Henry G. Stott, chairman of the Power Station Committee, under whose auspices the meeting was held.

Chairman Stott then called upon Mr. B. G. Lamme, the author of the paper of the evening, entitled *High-Speed Turbo-Generators—Designs and Limitations.* Mr. Lamme in presenting his paper gave a brief abstract of its objects and scope.

The paper was then discussed in detail by Chairman Stott and Messrs. Henry G. Reist, R. B. Williamson, Philip Torchio, Carl J. Fechheimer, William LeRoy Emmet, Paul M. Lincoln, Peter Junkersfeld, H. M. Hobart, W. L. Waters, Comfort A. Adams, and Allan B. Field. The technical session closed at 10:30 p.m. after much valuable discussion had been presented on the construction and limitations of various types of high-speed turbo-alternators. The members then adjourned to the Institute rooms on the tenth floor where the usual smoker was held.

Recommended for Transfer to the Grade of Member, January 2, 1913

The following Associates were recommended for transfer to the grade of Member by the Board of Examiners at its regular monthly meeting held on January 2, 1913. Any objection to these transfers should be filed at once with the Secretary:

HART, PERCY E., Estimating Engineer, Canadian General Electric Co., Toronto, Ont.

STREET, GEORGE T., Electrical Superintendent, San Domingo Light & Power Co., Puerta Plata, S. D.

Transferred to Grade of Fellow, January 10, 1913.

The following were transferred to the grade of Fellow of the Institute at the meeting of the Board of Directors on January 10, 1913.

KEITH, ALEXANDER E., Chief Engineer, Automatic Electric Co., Chicago, Ill.

LARDNER, HENRY A., Manager, J. G. White & Co., San Francisco, Cal.

Transferred to Grade of Member, January 10, 1913

The following Associates were transferred to the grade of Member of the Institute at the meeting of the Board of Directors on January 10, 1913.

Underhill, Charles R., Electrical Engineer, Acme Wire Company, New Haven, Conn.

Conn, Charles F., Assistant Manager, J. G. White & Co., San Francisco, Cal.

Associates Elected January 10, 1913

Adams, Christopher Andrew, Switchboard Operator, Chicago & Northwestern Ry. Co. Terminal; res., 3221 Warren Ave., Chicago, Ill.

Ahrens, Adolph G., Sales Engineer, Industrial Power Dept., Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Allen, Horace Ethan, Manager, Light, Heat and Power Dept., Toledo Railways & Light Co., Toledo, Ohio.

Atkins, George Leon, Special Apprentice in Electrical Dept., Harman Shops, N. Y. C. & H. R.R.; res., 137 Warburton Ave., Yonkers, N. Y.

Beck, Moses Maurice, Engineer, Viele, Blackwell and Buck, 49 Wall St., New York, N. Y.

Bennett, Morris Hunt, Assistant Superintendent, Meter Dept., Edison Electric Ill. Co., 14 Rockwell Place, Brooklyn, N. Y.

Berger, Julius George, Electrical and Mechanical Engineer, Small Motor Dept., General Electric Co., 30 Church St., New York, N. Y.

Booth, Jesse James, Railway Engineering Dept., Westinghouse Electric & Mfg. Co., Pittsburgh; res., 412 West St., Wilkinsburg, Pa.

Brannigan, Robert A., Manager Patent Dept., Automobile Board of Trade, 7 East 42nd St.; res., 419 West 119th St., New York, N. Y.

Cale, Wilfred Coveney, Transmission Line Engineer, Stone & Webster Engg. Corp'n., Keokuk, Iowa.

Chandler, Thomas, Superintendent, Edison Sault Electric Co., Sault Ste. Marie, Mich.

Childs, Robert Barney, Switchboard Operator, Great Falls Power Co., Great Falls, Mont.

Collopy, Bertram Cecil, Draftsman, Great Western Power Co., 233 Post St., San Francisco, Cal.

Crawford, James Antony, Electrician, Auckland Electric Tramways Co., Hobson St., Auckland, N. Z.

Curtis, Leslie Forrest, Instructor in Electrical Engineering, University of Washington; res., 5249 17th Ave., N. E., Seattle, Wash.

Doggett, Leonard Allison, Instructor in Electrical Engineering, Harvard University, Cambridge; res., 805 Broadway, South Boston, Mass.

Erickson, John, Mechanical and Electrical Engineer, Automatic Electric Co.; res., 3752 Herndon St., Chicago, Ill.

Eriksson, Karl Erik Gabriel, Electrical Engineer, 271 Hicks St., Brooklyn, N. Y.

Favorite, John Walter, Electrical Engineer, Fairbanks, Morse Electric & Mfg. Co.; res., 2052 College Ave., Indianapolis, Ind.

Ferrandou, Alfred Henry, Statistician, Federal Light & Traction Co., 60 Broadway, New York, N. Y.

Fischer, Eugene, Electrician in charge, Electrical Repair Dept., Yukon Gold Co., Dawson, Y. T.

Forshee, Isaac C., Electrical Engineer, Pennsylvania Railroad, Broad Street Station, Philadelphia, Pa.

Foster, Vernon Simons, Electrical Engineering Dept., Sprague Electric Works; res., 90 Ella St., Bloomfield, N. J.

Garcia, Emilio M., Illuminating Engineer, Mexican Light & Power Co., Apartado 490, Mexico, D. F.

Geary, Thomas W., Telephone Engineer, American Tel. & Tel. Co., 15 Dey St., New York, N. Y.

George, Frederick Robert, Chief Load Dispatcher, Pacific Gas & Electric Co.; res., 915 East 22nd St., Oakland, Cal.

Gibbony, A. G., Superintendent, Massena Electric Lt. & Pr. Co., 45 Main St., Massena, N. Y.

Howe, Edward Somerset, Electrical Engineer, Service Dept., Westinghouse Electric & Mfg. Co., 201 Devonshire St., Boston, Mass.

Hyatt, Albert Percy, Equipment Superintendent, Chicago Telephone Co., Chicago; res., 204 S. Taylor Ave., Oak Park, Ill.

Ingalls, Wilfred Liston, Specialty Salesman, Pacific States Electric Co., 90 7th St., Portland, Ore.

Innes, Frederick William, District Engineer, British Columbia Telephone Co.; res., 2537 Forbes St., Victoria, B. C.

Kelly, Edwin Walker, Chief Engineer, Roentgen Mfg. Co., 1210 Race St.; res., 5450 Pine St., Philadelphia, Pa.

Ketcham, Henry H., Electrical Engineer, Cutler-Hammer Mfg. Co., Milwaukee, Wis.

King, William Augustus, Special Agent, Contract Dept., Mexican Light & Power Co., Mexico, D. F.

Kirby, Henry Wright, Adams-Bagnall Electric Co.; res., 13798 Euclid Ave., Cleveland, Ohio.

Kuchel, Charles J., Electrical Draftsman, Southern Pacific Co., 1110 Flood Bldg., San Francisco, Cal.

Lee, Carl, Student Engineer, Testing Dept., General Electric Co.; res., 228 Liberty Street, Schenectady, N. Y.

MacAfee, Ralph Evans, Correspondent, Canadian Westinghouse Co., Calgary, Alberta.

Malone, Clyde Arthur, Manager, Ashland Electric Power & Light Co.; res., 93 Granite St., Ashland, Ore.

Mansbendel, Fritz Peter, Electrical Engineer, P. W. Sothman & Co., 17 Battery Place, New York, N. Y.

McAdam, Clarence Eugene, Lieutenant Phillipine Constabulary, Bureau of Constabulary, Manilla, P. I.

McClure, Milton Black, Electrical Engineer, General Electric Co.; res., 306 Lafayette St., Schenectady, N. Y.

Metcalfe, Virgil Ellsworth, 411 West 154th St., New York, N. Y.

Mold, Harvey James, Engineer, American Tel. & Tel. Co., 15 Dey St., New York, N. Y.

Newton, Edward Gillette, Engineer Power & Mining Co., General Electric Co., Schenectady, N. Y.

Oldacre, Marmion Sohl, Testing Engineer, Commonwealth Edison Co. 28 N. Market St.; res., 4744 Evans Ave., Chicago, Ill.

Parsons, Joe Blackburn, Student in Electrical Engineering, Purdue University, Lafayette, Ind.

Patterson, Robert M., Superintendent of Transmission, Chicago Railways Co., Room 700, 105 La Salle St., Chicago, Ill.

Plume, Robert Cecil, Jr., Manager Supply Dept., Mexican General Electric Co., Mexico City, Mex.

Putnam, William Rowell, Electrical Engineer, Dakota Power Co., Rapid City, South Dakota.

Rapier, Stephen A., Representative, Mexican General Electric Co., Apartado 403, Mexico, D. F.

Robinson, Lloyd N., Testman, General Electric Co., Schenectady, N. Y.

Rockwell, Robert Leonard, Head of Electrical Engineering Dept., Seattle Engineering School, Inc., Seattle, Wash.

Sahmel, Riggo, Consulting Engineer, 50 Church St., New York; res., 129 Pierpont St., Brooklyn, N. Y.

Smith, Carleton Whitney, Electrical Inspector, Boston Board of Fire Underwriters, 55 Kilby St., Boston, Mass.

Stanwick, Charles Arnes, Senior Electrical Student, University of Washington; res., 1508 24th Ave., Seattle, Wash.

Stoffel, Lester Lenneth, Laboratory Assistant, National Carbon Co.; res., 9816 Cudell Ave., N. W., Cleveland, Ohio.

Thomas, Everett Eri, Electrical Engineer, Testing Dept., General Electric Co., Schenectady, N. Y.

Tippin, Leslie Orvel, Inspector, Plant Dept., Chicago Telephone Co.; res., 1452 West Adams St., Chicago, Ill.

Trueman, Paul T., Electrical Draftsman, 60 Federal St., Boston, Mass.

Truex, Raymond M., Draughtsman, Electric Bond & Share Co., 71 Broadway; res., 217 W. 12th St., New York, N. Y.

Wanner, Roy Knouse, Electrical Engineer, Testing Dept., General Electric Co.; res., 602 Union St., Schenectady, N. Y.

Watt, Robert McDowell, Foreman of Electrical Construction, Kentucky Traction & Terminal Co.; res., 242 Market St., Lexington, Ky.

Whitehouse, Orville M., Electrical Engineer, Dutchess Branch, Garner Print Works & Bleachery, Wappinger Falls, N. Y.

Winetraub, Adolph I. M., Assistant Industrial Electrical Engineer, Westinghouse, Church Kerr & Co., 10 Bridge St., New York, N. Y.

Yamada, Yoshiho, Electrical Engineer, Oji Paper Mill, Tomakomai, Japan.

Young, Umberto, Inspector on Hydraulic Construction, Tucson Farms Co., Tucson, Ariz.

Total 67.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before February 28, 1913.

Albert, E. J., Cobalt, Ont.
Albert, W. P., Chicago, Ill.
Allen, C. C., Dallas,Texas.
Anraku, Y., Schenectady, N. Y.
Archer, E. G., Toronto, Ont.
Armstrong, E. A., East Lansing, Mich.
Arnold, L., (Member) Lynn, Mass.
Barnett, Louis, Brooklyn, N. Y.
Beck, V. S., Keokuk, Iowa.
Berg, A. L., Pittsfield, Mass.
Berssenbrugge, B., Milwaukee, Wis.
Birdsall, W. T., Montclair, N. J.
Bissel, M. H., Swissvale, Pa.
Black, D. C., Gloversville, N. Y.
Board, A. R., Kansas City, Mo.
Bossinger, H. C., Schenectady, N. Y.
Bourlon, A., Mexico City, Mex.
Boyles, R. A., Montreal, Que.
Brown, A. T., State College, Pa.
Butler, A. S., Cleveland, Ohio.
Cahan, J. F., Vancouver, B. C.
Campbell, C. W. R., Transvaal, S. A.
Chandler, W. A., Danville, Ill.
Costa, L. J., Philadelphia, Pa.
Cox, M. L., San Francisco, Cal.
Crellin, E. A., Portland, Ore.
Crowell, G. G. Wilkinsburg, Pa.
Davis, J. W., Nashville, Tenn.
Davison, A. E., Toronto, Ont.
Desloge, L., St. Louis, Mo.
DeTar, DeLos, Conway Springs, Kan.
Dill, G. C., Wilkinsburg, Pa.
Drake, R. E., New York, N. Y.
Durgin, M. F., Cambridge, Mass.
Eager, W. G., Valdosta, Ga.
Eichberg, F., (Fellow) Breslau, Ger.
Ferree, E. C., Coraopolis, Pa.
Ferris, L. P., New York, N. Y.
Field, R., Toronto, Ont.
Fregau, J. H., Montreal, Que.
Fritch, H. F., Attleboro, Mass.
Girdlestone, C. F., Cheshire, England.
Goebel, G. W., Wilkinsburg, Pa.
Goldsborough, J., East Orange, N.J.
Gregg, J. M., Chicago, Ill.
Harrison, R. H., Orange, N. J.
Haynes, H. A., Washington, D. C.
Higgins, D. D., Chicago, Ill.
Hill, G., Brooklyn, N. Y.
Hill, W. S., Milwaukee, Wis.
Hilsenbeck, J. B., Jenkins, Ky.
Hodgman, H. H. H., Pittsfield, Mass.
Hofman, G. W. Milwaukee, Wis.
Hubard, E. E., Mexico City, Mex.

Hunter, E. E., Oklahoma City, Okla.
James, D. G., Chicago, Ill.
Johnson, F. B., Chicago, Ill.
Johnson, J. R., Schenectady, N. Y.
Johnston, E. B., Oklahoma City, Okla.
Kincaid, C. W., Pittsburgh, Pa.
King, A. C., (Member) Chicago, Ill.
Kiyohara, I., Urbana, Ill.
Kujirai, T., Schenectady, N. Y.
Landon, R. R., Iloilo, P. I.
Larzelere, C.B., (Member)Culebra, C.Z.
Latimer, E. F., Toronto, Ont.
Leonard, V. Y., Albany, N. Y.
Madden, J. J. K., Pittsfield, Mass.
Matty, L. F., Mexico City, Mex.
Maxwell, G. R., Berkeley, Cal.
McDowell, C. S., Brooklyn, N. Y.
McDowell, H. W., Buffalo, N. Y.
Mead, F. B., Hamilton, Ont.
Melroy, K. D. Summit N. J.
Meyer, F. J. Oklahoma City, Okla.
Mitchell, W. C., Ann Arbor, Mich.
Myers, E. L., Mexico, D. F.
Obergfell, R. M., Lockport, Ill.
Orbison, T. E., Appleton, Wis.
Parker, E. C., Atlanta, Ga.
Petermann, R. L., Hammond, Ind.
Purcell, J. W., Toronto, Ont.
Redding, H. W., Schenectady, N. Y.
Regenstein, H. S., Pittsburgh, Pa.
Rice, C. M., Milwaukee, Wis.
Richardson, E. A., Middletown, Ohio.
Rivers, D. E., Harvey, Ill.
Salter, B. O., Toronto, Ont.
Schellens, C. A., Lynn, Mass.
Schiele, A. R., Cleveland, Ohio.
Schoonmaker,J.M.,Jr.,GrandMere,Que.
Snell, T. W., San Mateo, Cal.
Snow, V. A., Tucson, Ariz.
Snyder, H. T., Baltimore, Md.
Sorsby, P. C., Atlanta, Ga.
Springer, G. E., Bellingham, Wash.
Stillwell, E. D., Gatun, C Z.
Stoltz, G. E., Pittsburgh, Pa.,
Stover, S. M., Ponce, P. R.
Sullivan, A. H., Lincoln, Neb.
Truskett, E. E., Caney, Kan.
Ulrich, W. H., Baltimore, Md.
Wagschal, G., Toronto, Ont.
Weimer, G. O., Columbus, Ohio.
White, H. L., New York, N. Y.
Whitmore, A. C., Norris, Mont.
Whitney, R. F., Oswego, N. Y.
Wood, C. M., Denver, Colo.
Woodruff, F. C., Brooklyn, N.Y.
Wunsch, F., Philadelphia, Pa.
Total 110

Students Enrolled, January 10, 1913

5534 James, W. G.,Kan. State Agr.Coll.
5535 Leech, C. A.,Kan. State Agr. Coll.
5536 Newhouse,H.E.,Kans.St.Agr.Coll.
5537 Hulse,C.A.,Kansas State Agr.Coll.
5538 Butcher,H.E.,Kan.State Agr.Coll.
5539 Moss, F. E.,Kan. State Agr. Coll.
5540 Strain, C.D., Kan. State Agr. Coll.
5541 Buck, W. A., Kans. State Agr.Col.
5542 Gillespie,G.S.,Kan. State Agr. Col.
5543 Clark, O. R., Cornell University.
5544 Parker, M., Cornell University.
5545 Miller, J. G., Cornell University.
5546 Spencer, R., Cornell University.
5547 Sturrock, J. F., Cornell University.
5548 Wells, A. S., Cornell University.
5549 Rosswelt, G. H., Harvard Univ.
5550 Oehler, W. A., Univ. of Cincinnati.
5551 Young, R. L., Texas A. & M. Coll.
5552 Hefner, W. J., Texas A. & M. Coll.
5553 Kraege,A.C. A., Texas A.& M.Col.
5554 Hogue, E. N., Texas A. & M. Coll.
5555 Simon, R. B., Texas A. & M. Coll.
5556 Bowler, S. E., Texas A. & M. Col.
5557 Snyder, C. E.,Univ. of Pittsburgh
5558 Taylor, F. W., Lewis Institute.
5559 Flournoy,E.K.,Highland ParkCol.
5560 Khanna, J., Univ. of Pittsburgh.
5561 Hall, F.P.,Jr., Cornell University.
5562 Schmertz, P., Univ. of Pittsburgh.
5563 Miles, N. T., Lewis Institute.
5564 Kent, L. C., Univ. of Illinois.
5565 Novotny, C. O., Lewis Institute.
5566 Baker, F. C., Lewis Institute.
5567 McNair, J. S., Wash. State Coll.
5568 Meyers, C. H., Univ. of Oregon.
5569 Warner, H. P., Ohio North. Univ.
5570 Cholewinski,W., Lewis Institute.
5571 O'Brien, L. A., Kan. St. Agr. Coll.
5572 Abernathy, E.B.,Univ. of Okla.
5573 Glass, R. L., Univ. of Pittsburgh.
5574 Over, R.W., Univ. of Pittsburgh.
5575 Jimenez, A., Univ. of Pittsburgh.
5576 Bomar, H.J., Clemson Agr. Coll.
5577 Gentry, T. C., ClemsonAgr. Coll.
5578 Kangeter, J.H., Clemson Agr.Coll.
5579 Lawton, M. S., ClemsonAgr. Coll.

5580 Berry, M.D., Clemson Agr. Coll.
5581 Brown, S. K.,Clemson Agr. Coll.
5582 Morrison,W.E.,Clemson Agr.Coll.
5583 Provost, E. T.,Clemson Agr. Coll.
5584 McGee, H.S.,Clemson Agr. Coll.
5585 Sloan, D.M.,Clemson Agr. Coll.
5586 Blackman, L.R.,Clemson Agr.Col.
5587 Griffith,G.F., Ohio NorthernUniv.
5588 Scott, A.G.,Case School Appl.Sci.
5589 Miller, W., Purdue University.
5590 Seccombe, F. R., Univ. of Cal.
5591 Kleinberg, A., Ohio State Univ.
5592 Hoppmann,R.B., Ohio StateUniv.
5593 Dale, L. O., Univ. of Illinois.
5594 Hall, L. M., Univ. of Illinois.
5595 Cook, A. S., Univ. of Toronto.
5596 Gambrill, W. N., Lehigh Univ.
5597 Davis, A. H., Univ. of Cincinnati.
5598 Kendall, R. T. Univ. of Mich.
5599 Waite, L. O., Univ. of Michigan.
5600 Boult, J. B., Univ. of Michigan.
5601 Martz, C. A., Univ. of Nebraska.
5602 Arms, L. P., Univ. of Nebraska.
5603 Skan, W. A. M., Lewis Institute.
5604 McKinney, H.D., Univ. of Colo.
5605 Uyeda, S., Univ. of Colorado.
5606 Armos, C. A., Univ. of Colorado.
5607 Winter, B. W., Univ. of Colorado.
5608 Brace, P. H., Univ. of Colorado.
5609 Kelm, A. C., Univ. of Wisconsin.
5610 Moody, R. E., Univ. of Wisconsin.
5611 Johns, F. W., Univ. of Wisconsin.
5612 Jones, W. C., Colorado College.
5613 Miller, R. A., Case School Science.
5614 Draper, F. E.,Univ. of South.Cal.
Total 81

The Myriawatt Recommended as a Power Unit by Joint Committees of the A. S. M. E. and A. I. E. E.

At a joint meeting of the Standards Committee of the American Institute of Electrical Engineers, and a committee especially appointed for the conference by the American Society of Mechanical Engineers, on December 13, 1912, at the Engineering Societies Building, New York, the following resolutions were unanimously adopted, and have been duly reported to the governing boards of the two above-mentioned engineering societies:

Whereas, the "myrowatt" or "myriawatt" was suggested by Mr. H. G. Stott as a convenient unit of power only 2 per cent larger than the most recently determined values of the "boiler horse power," and

Whereas, a paper setting forth the advantages of the use of the "myriawatt" as a unit of power in dealing with the performance of steam boilers, steam engines, gas engines, steam and water turbines, was read by Messrs. H. G. Stott and Haylett O'Neill before the annual convention in Boston of the American Institute of Electrical Engineers in June, 1912, was discussed, and was published in the PROCEEDINGS of the Institute, and

Whereas, the American Society of Mechanical Engineers has appointed a special committee to confer with the Standards Committee of the American Institute of Electrical Engineers upon this unit, as presented in the said paper, be it

Resolved, (1) That the two committees in joint session recommend to their respective societies the use of the "myriawatt" as unit of thermal or mechanical power, as indicated in the above-mentioned paper.

(2) That the two committees also jointly recommend to their respective societies the exclusive use of the myriawatt in connection with boilers, producers, turbines and engines and discontinue the use of the term "boiler horse power."

(3) That Mr. C. O. Mailloux, as representing Mr. H. G. Stott on the special committee on Prime Movers recently appointed by the International Electrotechnical Commission, which committee is scheduled to meet at Zurich, Switzerland, on January 18, 1913, shall be and hereby is requested to bring these joint resolutions formally to the notice of that body in Zurich.

(4) That the two committees jointly recommend that in writings and publications the "myriawatt" and "myriawatt-hour" be abbreviated to mw. and mw-hr. in conformity with the existing abbreviations kw. and kw-hr. for kilowatt and kilowatt-hour, respectively.

The above resolutions are very important for two reasons; namely, (1) because this is the first piece of joint standardization work that has been accomplished by two of the national engineering societies having their homes in the Engineering Societies Building of New York City, and it is to be hoped that this may be the starting point for much good joint action of a similar nature by all of the national engineering societies, and (2) because the resolutions indicate and recommend a simple and satisfactory method of rating the input and output of turbo-generators, in terms of one and the same unit—the international watt. Instead of rating the output of a turbo-generator in kilowatts, and the input in boiler horse power or other heat units as at present, it becomes very convenient to rate the electric output in kilowatts, and the steam input in myriawatts, because the myriawatt is approximately the same as the boiler horse power, while it is also exactly 10 kilowatts. By this means the long-existing incongruity of stating the input and output in different and disconnected units of power will be eliminated.

Past Section Meetings

BALTIMORE

The December meeting of the Baltimore Section, on December 20, 1912, was preceded by a dinner served in the grill room of the New Howard Hotel. The dinner was followed by a symposium on Industrial Power. The subject was presented by five speakers, as follows: Mr. R. H. Tillman, " Outline of Industrial Applications in Baltimore;" Mr. W. H. Ulrich, " Electricity in Hotels;" Mr. T. D. Rose, " Electricity in Office Buildings;" Mr. F. M. Weller, " Electricity in the Fertilizer Industry;" and Mr. A. B. Grubmeyer, " Electric Refrigeration."

The very great advance in the uses of electricity for industrial power in Baltimore in the last few years was emphasized by the speakers. The discussion following the symposium was taken part in by Messrs. C. G. Edwards, William H. Hall, W. D. Young and L. M. Potts.

In the absence of Dr. J. B. Whitehead, Mr. Douglas Burnett presided at the meeting, at which there was an attendance of forty-five.

CLEVELAND

The Cleveland Section met at the plant of the Electric Welding Products Company, on December 16, 1912, with Mr. J. C. Lincoln presiding in the absence of Chairman Edwards. The attendance was 80 (35 members, 10 students and 35 visitors).

Preceding the meeting an inspection of the plant was made, during which the Thomson process of electric welding was seen in operation, turning out automobile and other machine parts in a great variety of shapes and using different grades of metal.

An equally interesting feature was the demonstration of the uses of the oxy-acetylene welding and cutting equipment of the Metals Welding Company in making butt welds on plates, welding a thin cast-iron face on steel gas-engine valves and in cutting off I-beam sections with the oxidizing flame.

After the inspection of the machine shop equipment and heat-treating furnaces, the Section listened to a paper by Mr. William H. Spire, of the Electric Welding Products Company, on " Electric Welding ", and one by Mr. E. C. Reader, of the Metals Welding Company, on " Oxy-Acetylene Welding," with discussion by Mr. John Harris. These papers described in greater detail the processes seen during the trip through the factory. The papers were discussed briefly by several members. Several specimens of arc welding were exhibited after the meeting.

DETROIT—ANN ARBOR

A meeting of the Detroit-Ann Arbor Section was held on December 18, 1912, in Employers' Association Hall, Detroit. Chairman J. J. Woolfenden presided, and there was a total attendance of 28. The chairman announced the appointment of the following standing committees: membership—C. J. Wallace, chairman, G. S. Van Norman, C. E. Wise; papers—R. D. Parker, chairman, H. L. Tanner, vice-chairman, E. L. Bailey, G. E. Lewis; entertainment—E. P. Decker, chairman, R. W. Hemphill, Jr., E. C. Chambers; reception—L. F. Myrphy, chairman, F. J. Mistersky, Dr. H. J. Schmitz; press—A. T. Barley, chairman, J. F. Wilson; librarian—H. S. Williams.

A paper on " Motor Controlling Problems " was presented by Mr. F. R. Fishback, manager of the Electric Controller and Manufacturing Company, Cleveland, Ohio.

FORT WAYNE

A meeting of the Fort Wayne Section was held on December 19, 1912, in the rooms of the Fort Wayne Commercial Club. The vice-chairman, Mr. T. W. Behan, presided, and there was an attendance of fifteen at the meeting. The resignation of the chairman, Mr. A. B. Morrison, Jr., was read and accepted.

The subject of the evening was " The Applications of Fractional Horse Power Motors." Mr. P. O. Smith led the discussion, giving a complete outline of the subject, dividing the motors into types, and discussing the suitability of the various types for the requirements of different applications.

LOS ANGELES

The Los Angeles Section held a joint meeting with the Engineers and Architects Association of Southern California and the Electrical League of Southern California in Choral Hall, Temple Auditorium, on December 17, 1912. A dinner was served at the Oriental Cafe, before the regular meeting. There were present 250 members and visitors, including ladies. Chairman George A. Damon was in the chair.

Mr. W. D'A. Ryan of Schenectady, who is in California to plan the illumination of the expositions to be held at San Francisco and San Diego in 1915, gave a talk on " Illumination," predicting that something new in the illuminating field would be seen at the coming expositions. He performed numerous experiments to show the effects produced by long and short waves of light, and the talk was profusely illustrated, showing the different modes of illumination used at expositions, on city streets and at Niagara Falls.

LYNN

A meeting of the Lynn Section was held on December 4, 1912, in Burdett College Hall, Chairman W. A. Hall presiding. Mr. Charles F. Prichard, vice-president and general manager of the Lynn Gas and Electric Company, gave a talk on " Gas, Its Uses and Possibilities." On account of Mr. Prichard's connection with both the gas and electrical business, he was able to make interesting comparisons. The lecture was illustrated by more than fifty lantern slides, a large number of which had been especially prepared for the meeting. There were present at this meeting 221 members and 27 visitors.

The Lynn Section has adopted a local badge or identifying button for members of the Section, and these were first put on sale at this meeting.

On December 18 a meeting of the Section was held at the G. E. Restaurant, West Lynn. The secretary, Mr. E. R. Berry, presided, and there was an attendance of 225, of whom 54 were visitors.

Mr. F. P. Cox, engineer of the meter and instrument department, General Electric Company, talked on the subject of meters, and was assisted by Messrs. Pratt, Hamann, West and Lloyd. Mr. Lyman Arnold of the transformer department covered the subject of instrument transformers. The talks were well illustrated with lantern slides. In a room adjacent to the hall there had been arranged an interesting exhibit of meters which showed the progress in development from the earliest commercial types to those now being manufactured.

MADISON

A meeting of the Madison Section was held on December 12, 1912, in the engineering building of the University of Wisconsin. Chairman E. H. Kifer presided, and there was a total attendance of 31. Mr. J. L. Buchanan of the transformer department of the General Electric Company presented a paper entitled " Transformers, Lightning Arresters, and Ozonators; Their Development and Application." The paper was well illustrated by lantern slides showing the constructional details and development of this class of apparatus.

MEXICO

A meeting of the Mexico Section was held on January 2, preceded by a dinner at the Salon Bach, Mexico City. Chairman H. S. Foley presided, and there was a total attendance of 30. Mr. James Carson, contract agent of the Mexican Light and Power Company, Limited, presented a paper entitled "Electrical Publicity." Mr. Carson handled the subject from two sides, the use of publicity in increasing the demand for electric light, power and heat, and the use of electric light, itself, as a medium of publicity.

MILWAUKEE

The December meeting of the Engineers Society of Milwaukee and the Milwaukee Section of the A. I. E. E. was held on December 18, 1912, at the Plankinton House. Mr. Henry Weickel presided.

Mr. W. R. Roberts of the Roberts and Schaeffer Company, of Chicago, presented a paper on "Briquetting." The paper dealt with the commercial briquetting of coal. As an introduction Mr. Roberts explained the various methods employed abroad in briquetting coal, and the reasons which forced the foreign engineers to take up the subject. He showed with what diligence and care they had developed the processes, and attributed the failure of many of the American plants to the fact that the American engineers did not profit by the data obtained by the foreign engineers. He then exhibited views of some of the successful plants in operation in this country and described two in detail. Views of the various types of briquetting machines were also shown. As a conclusion, Mr. Roberts gave the requisites for a successful commercial briquetting plant, and showed the great extent of the field for this industry in this country.

The paper was followed by a discussion in which some interesting facts were brought out in regard to tests of briquettes as fuel for locomotives.

The meeting was attended by about 80, and was followed by a buffet luncheon.

The next monthly meeting of the Milwaukee Section was held in conjunction with the Engineers Society of Milwaukee on January 6. Mr. John W. Alvord gave a talk on "Sewage Disposal of the City of Milwaukee," illustrated by special lantern slides. Mr. Alvord described the different types of sewage disposal plants in successful operation. He then went into the subject of a sewage disposal plant for Milwaukee and presented some interesting slides and data which gave his hearers a clear conception of what must be done in Milwaukee to protect the water supply. Mr. Alvord was one of the three experts called in by the city in 1911 to make a complete study of the situation.

At this meeting there was an attendance of 55 members and 125 visitors. Mr. Weickel presided.

MINNESOTA

A meeting of the Minnesota Section was held on December 9, 1912, at the Ryan Hotel, St. Paul. Mr. A. L. Abbott presided, and there was a total attendance of 30. The meeting was preceded by the customary informal dinner.

The meeting was devoted to the subject of substation design. Mr. H. Stanley of H. M. Byllesby and Company gave an illustrated lecture, showing different substation designs used by his company. Mr. J. C. Vincent described the substations of the Twin City Rapid Transit Company, presenting a number of sketches in illustration. Mr. E. P. Burch then presented a paper entitled "A Review of the Electric Railway Substation Situation."

PHILADELPHIA

On January 9 the Philadelphia Section held a joint meeting with the

Franklin Institute. There was an attendance of 100, and Messrs H. A. Hornor and W. C. L. Elgin presided.

Mr. W. L. R. Emmet presented a paper on "The Electric Propulsion of Ships," which was discussed by Messrs. Hornor, Eglin, Riggs and Naval Constructors Snow and Linnard.

On January 13, at the Engineers' Club, there was held a joint meeting of the Philadelphia Section of the A. I. E. E., the Illuminating Engineering Society and the National Electric Light Association. The meeting was preceded by an informal dinner. There was a total attendance of 128, and the presiding officers were Messrs. H. A. Hornor, A. J. Rowland and B. Frank Day.

Papers on "Modern Illumination" were presented by Messrs. J. D. Israel, G. A. Hoadley and A. J. Rowland, and the subject was discussed by Messrs. Day, Calvert, Robinson, Ely, Pierce, Swanfeld and Dr. Crampton.

The technical meeting was followed by a smoker at which an entertainment, prepared by Mr. Israel, chairman of the entertainment committee, was given by members of the societies.

The appointment was announced of Mr. H. Mouradian as manager, to fill the vacancy on the council caused by Mr. Hornor's election as chairman.

PITTSBURGH

A joint meeting of the Pittsburgh Sections of the A. I. E. E. and the Illuminating Engineering Society was held on December 12, 1912, in the rooms of the Engineers Society of Western Pennsylvania. Mr. E. L. Farrar and Professor H. S. Hower presided, and there was an attendance of 40.

The subject discussed was "Street Lighting." A paper on "Gas and Gasoline Lighting," in the absence of its author, was read by Professor Hower. The second paper was presented by Mr. C. E. Stephens, on "The Illumination Requirements of First-Class Streets as Met by Arc and Tungsten Light Sources." A paper by Mr. C. A. B. Halvorson, "New Types of Ornamental Luminous Arc Lamps for the Lighting of Parkways, Business and Residential Streets," was read by Mr. C. J. Mundo. These papers were discussed by Messrs. H. N. Mueller, Berford Brittain, W. E. Reed, Alan Bright, Darrah and Magdsick.

PITTSFIELD

On December 19, 1912, a meeting of the Pittsfield Sections was held at the Hotel Wendell, with an attendance of 125, of whom 25 were visitors. Mr. W. C. Smith presided. Mr. E. F. Gehrkens, of the transformer department of the General Electric Company, gave an illustrated lecture on "Regulators." He discussed their historical development, operation and manufacture.

On the evening of January 7, in place of the regular technical meeting, the Pittsfield Section held an informal dance and whist, at Osceola Hall. Some fifty couples were present. The affair was in charge of the entertainment committee, Mr. H. H. Hodgman, chairman.

PORTLAND, ORE.

The third regular meeting of the Portland Section was held in the club rooms of the Hawthorne Building, December 17, 1912, Mr. H. R. Wakeman presiding.

Considerable routine business was transacted, after which Mr. F.D.Gilbert of the Oswego-Portland Cement Company presented a paper on "Electricity as a Factor in the Development of the Cement Industry." The attendance was 15, including three visitors.

ST. LOUIS

The regular December Meeting of the St. Louis Section was held in the Engineers' Club rooms, on December 11, and was attended by about 50 members and guests. Mr. Joseph A. Osborn presided.

Mr. Herman Spoehrer presented a paper on "Central Station Statistics and Accounting," illustrated with numerous lantern slides. These show in a general way in what minute detail statistics of power cost and generation must be kept in the modern large power station.

Curves were also shown, giving the results of a careful study of the effect that a change in the base rate produces on the energy consumption and the monthly bills of various classes of consumers. In the particular case studied, a reduction in the rate produced a slowly increasing average consumption of energy, but a slight reduction in the net amount of the monthly bill. This reduction in income was more than offset by the increase in new business attracted by the lower rate.

A detailed study of various classes of consumers, such as was described by the author of this paper, would ordinarily involve an immense amount of clerical work. Use had been made, however, of the Hollerith tabulating machine, such as is used in the United States Census Bureau, and this had simplified the work of obtaining the various statistics described. One of these machines was on display to demonstrate its operation and use.

SCHENECTADY

A meeting of the Schenectady Section was held on December 4, 1912, in Red Men's Hall, with an attendance of 170. Mr. John B. Taylor presided. The speaker of the evening, Mr. H. G. Stott, superintendent of motive power of the Interborough Rapid Transit Company, New York, presented a paper entitled "Efficiency and Engineering," which is reprinted elsewhere in Section I.

The 117th meeting of the Schenectady Section, and the first of the discussion meetings of this season, was held in the Congregational Church Hall on the evening of December 17, 1912. The general subject of discussion was "The Generation of Power in Large Central Stations."

The subject was presented in a number of short talks by engineers whose work was closely connected with the different departments related to the main subject.

Mr. R. E. Argersinger presented the subject of regulators and voltage regulation, giving a brief outline of the different systems used in large central stations.

Mr. G. R. Parker discussed the very rapid growth of the steam turbine, which has taken place practically within the last decade. The great advantage of the modern steam turbine over any other steam prime mover is the ability of this class of apparatus to utilize steam throughout greater thermal limits. Even though the cost per kilowatt of the steam turbine were greatly in excess of even the best corliss engines and direct-connected alternators, the turbine would still hold first place, due to this feature of utilizing the heat in the steam throughout greater thermal limits. Throughout the history of the steam turbine the tendency has been to use higher initial pressures, higher superheat and higher vacuum in the condensers.

Mr. Emil G. Bern discussed switchboards and the adaptability of the different types to particular conditions.

Mr. E. A. Lof outlined the use of the different types of relays in relation to the protection of electrical apparatus from short circuits.

Mr. H. W. Peck and Mr. H. M. Hobart outlined the various rate systems used in charging for electrical energy. It was shown that the rate that should be charged for electrical energy varied with each power installation and that one system of rates which may be correct for one power installation may not necessarily be correct for another which is operated under different conditions.

Discussion of these various points was further carried on by Messrs. John B. Taylor, A. H. Kruesi, J. A. Dewhurst, C. Macmillan and H. R. Summerhayes.

There was an attendance of 100 at this meeting, at which Mr. J. R. Craighead presided.

At the meeting of the Section on January 7, held in Red Men's Hall, Mr. Sydney W. Ashe, of the Harrison lamp works of the General Electric Company, was the speaker. Mr. Ashe in his lecture first gave a brief history of the early work of Mr. Thomas A. Edison, emphasizing his close relationship to the development of the art of electric illumination. The remainder of his talk was devoted to an exposition of modern illumination, illustrated by lantern slides and numerous experiments.

There was an attendance of 285 at this meeting, at which Mr. John B. Taylor presided.

SEATTLE

The Seattle Section held a meeting on December 14, 1912, in the assembly hall of the Chamber of Commerce, that was attended by 30 persons. Mr. J. D. Ross presided.

The paper of the evening, "Notes on Modern Telephone Practise," by Messrs. T. F. Cales and L. P. Crim, was read by Mr. Cales, and a discussion followed, by Messrs. Crim, Hoff, Naugle, Terrell, Newell, Magnusson and others.

TOLEDO

The regular monthly meeting of the Toledo Section was held on January 10, at the Toledo Commerce Club.

Mr. B. J. Denman, chief engineer of power plants of the Edison Illuminating Company of Detroit, addressed the meeting on "New Developments in the Design, Construction and Operation of Large Power Plants." In his lecture the speaker discussed power houses Nos. 1, 2 and 3 of the Delray plant, which covers 40 acres of ground. The foundations of the smoke stacks and the power houses were shown and discussed. Lantern slides of the large boiler and turbine installation were also shown, the speaker giving the various efficiencies for boiler ratings from 80 per cent to 250 per cent. The replacement of the 3000-kw. turbines by 10,000-kw. turbines and the installation of the new 14,000-kw. and 16,000-kw. units, with the auxiliaries, were also described.

The lecture was discussed by Messrs. Gilmartin, Kirk, Long, Seeger, Rabbe and Roger.

There was an attendance of 32 at the meeting, at which Mr. George E. Kirk presided.

URBANA

On December 13, 1912, the Urbana Section held a smoker jointly with the Electrical Engineering Society of the University of Illinois. Several members of the Section spoke on the advantages of student affiliation with the Institute, and plans were discussed for the electrical show soon to be given.

Personal

MR. R. J. ANDRUS has been made vice-president and general manager of the Northwest Electric and Water Works, with headquarters at 614 New York Building, Seattle, Wash.

MR. ARTHUR WALSER has been transferred from the Philadelphia office of the Fort Wayne Electric Works to the Denver, Colo., office of the General Electric Company, power and mining department, in the First National Bank Building.

MR. A. J. LOEB has been made district manager for the American Rotary Valve Company of Chicago, Ill., with offices in the New England Building, Cleveland, Ohio, and will have charge of the engineering and sales of products of that company in his district.

MR. OSMUND M. JORSTAD, who has been in the employ of the Westinghouse Electric and Manufacturing Company for the last seven years, has severed his connection with that company and is now connected with the Chicago Association of Commerce Committee of Investigation on Smoke Abatement and Electrification of Railway Terminals.

OFFICERS AND BOARD OF DIRECTORS, 1912-1913.

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(Term expires July 31, 1913.)
RALPH D. MERSHON.

JUNIOR PAST-PRESIDENTS.

DUGALD C. JACKSON.
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(Term expires July 31, 1913.)	(Term expires July 31, 1914.)
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(Term expires July 31, 1913.)	(Term expires July 31, 1914.)	(Term expires July 31, 1915.)
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*NORVIN GREEN, 1884-5-6.
*FRANKLIN L. POPE, 1886-7.
T. COMMERFORD MARTIN, 1887-8.
EDWARD WESTON, 1888-9.
ELIHU THOMSON, 1889-90.
*WILLIAM A. ANTHONY, 1890-91.
ALEXANDER GRAHAM BELL, 1891-2.
FRANK JULIAN SPRAGUE, 1892-3.
EDWIN J. HOUSTON, 1893-4-5.
LOUIS DUNCAN, 1895-6-7.
FRANCIS BACON CROCKER, 1897-8.
A. E. KENNELLY, 1898-1900.
CARL HERING, 1900-1.
CHARLES P. STEINMETZ, 1901-2.
CHARLES F. SCOTT, 1902-3.
BION J. ARNOLD, 1903-4.
JOHN W. LIEB, JR., 1904-5.
SCHUYLER SKAATS WHEELER, 1905-6.
SAMUEL SHELDON, 1906-7.
HENRY G. STOTT, 1907-8.
LOUIS A. FERGUSON, 1908-09.
LEWIS B. STILLWELL, 1909-10.
DUGALD C. JACKSON, 1910-11.
GANO DUNN, 1911-12.

*Deceased.

HONORARY SECRETARY.	GENERAL COUNSEL.
RALPH W. POPE, 33 West 39th Street, New York.	PARKER and AARON, 52 Broadway, New York

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Revised to February 1, 1913

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General Electric Company, Schenectady, N. Y.
A. W. BERRESFORD, Milwaukee, Wis.
W. S. RUGG, New York.

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198½ Schermerhorn Street, Brooklyn, N.Y.
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PHILANDER BETTS, Newark, N. J.
DUGALD C. JACKSON, Boston, Mass.
MALCOLM MAC LAREN, Princeton, N. J.

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Revised to February 1, 1913.

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Baltimore.........Dec. 16, '04	J. B. Whitehead.	L. M. Potts, Industrial Building, Baltimore, Md.
Boston............Feb. 13, '03	Fred. P. Valentine.	Leavitt L. Edgar, 39 Boylston St., Boston, Mass.
Chicago..................1893	Ralph H. Rice.	E. W. Allen, 1028 Monadnock Building, Chicago, Ill.
Cleveland.........Sept. 27, '07	E. J. Edwards.	R. B. Chillas, Jr., National Carbon Co., Cleveland, Ohio.
Detroit-Ann Arbor.Jan. 13, '11	J. J. Woolfenden.	Ray K. Holland, Cornwall Building, Ann Arbor, Mich.
Fort Wayne.......Aug. 14, '08	T. W. Behan.	P. H. Haselton, Fort Wayne Electric Works. Ft. Wayne, Ind.
Indianapolis-Lafayette.Jan. 12, '12	O. S. More.	Charles A. Tripp, 710 Majestic Building, Indianapolis, Ind.
Ithaca............Oct. 15, '02	E. L. Nichols.	George S. Macomber, Cornell University, Ithaca, N. Y.
Los Angeles.......May 19, '08	G. A. Damon.	E. R. Northmore, Los Angeles Gas and Electric Company, Los Angeles, Cal.
Lynn.............Aug. 22, '11	W. A. Hall.	E. R. Berry, General Electric Co., Lynn, Mass.
Madison..........Jan. 8, '09	E. H. Kifer.	F. A. Kartak, Univ. of Wisconsin, Madison, Wis.
Mexico...........Dec. 13, '07	H. S. Foley.	James Carson, Mexican Light and Power Company, Mexico City, Mexico.
Milwaukee........Feb. 11, '10	T. E. Barnum.	L. F. Reinhard, Mechanical Appliance Co., Milwaukee, Wis.
Minnesota........Apr. 7, '02	A. L. Abbott.	Fred A. Otto, St. Paul Gas Light Co., St. Paul, Minn.
Philadelphia.......Feb. 18, '03	H. A. Hornor.	H. F. Sanville, 1326 Chestnut St., Philadelphia, Pa.
Pittsburgh........Oct. 13, '02	E. L. Farrar.	M. C. Turpin, Department of Publicity, W. E. and M. Company, Pittsburgh, Pa.
Pittsfield..........Mar. 25, '04	W. C. Smith.	W. W. Lewis, General Electric Company, Pittsfield, Mass.
Portland, Ore......May 18, '09	H. R. Wakeman.	G. P. Nock, Pacific Tel. and Tel. Co., Portland, Ore.
San Francisco.....Dec. 23, '04	H. W. Crozier.	A. G. Jones, 819 Rialto Building, San Francisco, Cal.
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Toronto...........Sept. 30, '03	F. A. Gaby.	H. T. Case, Continental Life Bldg., Toronto, Ont.
Urbana...........Nov. 25, '02	A. M. Buck.	F. G. Willson, University of Illinois, Urbana, Ill.
Vancouver........Aug. 22, '11	F. D. Nims.	E. M. Breed, Allis-Chalmers-Bullock, Ltd., Vancouver, B. C.
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Revised to February 1, 1913.

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Arkansas, Univ. of......Mar. 25, '04	W. B. Stelzner.	G. W. Watkins, Room 25, Buchanan Hall, Fayetteville, Ark.
Armour Institute........Feb. 26, '04	W. Fryberg.	R. L. Walsh, Armour Inst. Tech., Chicago, Ill.
Bucknell University ....May 17, '10	E. M. Richards.	Robert L. Rooke, Bucknell University, Lewisburg, Pa.
California Univ. of......Feb. 9, '12	Charles Grunsky.	C. I. Kephart, University of California, Berkeley, Cal.
Cincinnati, Univ. of......Apr. 10, '08		
Clemson Agricultural College.................Nov. 8, '12	J. H. Kangeter.	H. J. Bomar, Clemson College, S. C.
Colorado State Agricultural College.........Feb. 11, '10	Robert O. Sewell.	R. K. Havighorst, Colorado State Agricultural College, Fort Collins, Colo
Colorado, Univ. of.......Dec. 16, '04	Harry McKinney.	Seizo Uyeda, 1075 12th St., Boulder, Colo.
Highland Park College..Oct. 11, '12	J. W. Spooner.	Ralph R. Chatterton, Highland Park College, Des Moines, Iowa
Iowa State College......Apr. 15, '03	H.C.Bartholomew	F. A. Robbins, Iowa State College, Ames, Iowa.
Iowa, Univ. of..........May 18, '09	L. F. Hatz.	A. H. Ford. University of Iowa, Iowa City, Ia.
Kansas State Agr. Col....Jan. 10, '08	C. A. Leech.	W. C. Lane, Kansas State Agric. Col., Manhattan Kan.
Kansas, Univ. of........Mar. 18, '08	S. S. Schooley.	A. J. Fecht, Univ. of Kansas, Lawrence, Kan.
Kentucky, State Univ. of Oct. 14, '10	R. B. Pogue.	W. M. Lane, 216 Rose Street, Lexington, Ky.
Lafayette College.......Apr. 5, '12	F. W. Maue.	W. O. Hay, Jr. Lafayette College, Easton, Pa.
Lehigh University.......Oct. 15, '02	W. J. Dugan.	E. F. Weaver, Lehigh University, S. Bethelhem, Pa.
Lewis Institute..........Nov. 8, '07	Ralph Kilner.	A. H. Fensholt, Lewis Institute, Chicago, Ill.
Maine, Univ. of.........Dec. 26, '06	Howard O.Burgess	J. Larcom Ober, S. A. E. House, Orono, Maine.
Michigan, Univ. of......Mar. 25, '04	Ward F. Davidson	Edward A. Roeser. Univ. of Michigan, Ann Arbor, Mich.
Missouri, Univ. of.......Jan. 10, '03	H. B. Shaw.	E. W. Kellogg, 9 Engineering Building, Columbia, Mo.
Montana State Col......May 21, '07	Lawrence Wylie.	J. A. Thaler, Montana State College, Bozeman, Mont

LIST OF BRANCHES.—Continued.

Name and when Organized.	Chairman.	Secretary.
Nebraska, Univ. of......Apr. 10, '08	Geo. H. Morse.	V. L. Hollister, Station A, Lincoln, Nebraska.
New Hampshire Col.....Feb. 19, '09	Robin Beach.	Clayton W. Work, New Hampshire College, Durham, N.H.
North Carolina Col. of Agr. and Mech. Arts...Feb. 11, '10	S. B. Sykes.	J. W. Johnson, N. C. College of A. and M. Arts, West Raleigh, N. C.
Ohio Northern Univ.....Feb. 9, '12	F. M. Billhimer.	J. E. Wineland, Ohio Northern University, Ada, Ohio.
Ohio State Univ.........Dec. 20, '02	R. E. Kinkead.	T. O. Farmer, Ohio State Univ., Columbus, Ohio.
Oklahoma Agricultural and Mech. Coll.......Oct. 13, '11	A. P. Little.	J. W. Harvey, 416 Hester Street, Stillwater, Okla.
Oklahoma, Univ. of.....Oct. 11, '12	David E.Renshaw	Leo H. Gorton, 526 UniversityBoulevard,Norman.Okla.
Oregon Agr. Col........Mar. 24, '08	Lance Read.	Charles E. Oakes, Oregon Agric. Col., Corvallis, Ore.
Oregon, Univ. of........Nov. 11, '10	R. H. Dearborn.	C. R. Reid, Univ. of Oregon, Eugene, Oregon.
Penn State College......Dec. 20, '02	K. P. Fuhrman.	I. S. Nippes, Pennsylvania State College, State College, Pa.
Purdue Univ...........Jan. 26, '03	C. F. Harding.	A. N. Topping, Purdue University, Lafayette, Ind.
Rensselaer Poly. Inst..Nov. 12, '09	E. D. N. Schulte.	W. J. Williams, Rensselaer Poly. Institute, Troy, N. Y
Rose Polytechnic Inst...Nov. 10, '11	S. Irwin Stocking.	Joseph E. O'Connell, 457 N. 8th Street, Terre Haute, Ind.
Stanford Univ..........Dec. 13, '07	Linford C. Lull, Jr.	Walter J. Dodge, Stanford University, California.
Syracuse Univ..........Feb. 24, '05	W. P. Graham.	R. A. Porter, Syracuse University, Syracuse, N. Y.
Texas, Univ. of.........Feb. 14, '08	J. A. Correll.	N. H. Brown, University of Texas, Austin, Tex.
Throop Poly. Inst.......Oct. 14, '10	Ray Gerhart.	R. W. Parkinson, Throop Poly. Institute, Pasadena, Cal.
Univ. of Washington....Dec. 13, '12	George Tripple.	S. R. Shave, Univ. of Washington, Seattle, Wash.
Vermont, Univ. of.......Nov. 11, '10	Walter L. Upson.	O. Krupp, 65 North Bend St., Burlington, Vt.
Virginia, Univ. of........Feb. 9, '12	Walter S.Rodman	Henry Woodman Clark, A. X. P. House, University, Virginia.
Wash., State Coll. of....Dec. 13, '07	M. K. Akers.	H. V. Carpenter, State Col. of Wash., Pullman, Wash.
Washington Univ.......Feb. 26, '04	C. E. Wright.	A. S. Blatterman, Washington University, St. Louis, Mo
Worcester Poly. Inst...Mar. 25, '04	Harry B. Lindsay.	George I. Gilchrest, Worcester Poly. Inst., Worcester, Mass.
Yale University.........Oct. 13, '11	R. H. Willard, Jr.	M. R. Wibberley, 136 Vanderbilt-Scientific, New Haven, Conn.

Total, 46.

PROCEEDINGS
OF THE
American Institute
OF
Electrical Engineers.

Published monthly by the A. I. E. E., at 33 W. 39th St., New York, under the supervision of

THE EDITING COMMITTEE

GEORGE R. METCALFE, Editor

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Vol XXXII **March, 1913** No. 3

Midwinter Convention

Preparations are completed for the Midwinter Convention, February 26-28, under the auspices of the Standards Committee, and at the time of going to press over three hundred have already signified their intention of attending the convention.

A complete report of the Midwinter Convention will be printed in the April PROCEEDINGS.

Regular March Meeting of the A. I. E. E. in New York, March 14, 1913

The two-hundred and eighty-first meeting of the A. I. E. E. will be held in the auditorium of the Engineering Societies Building, New York, March 14, 1913, at 8:15 p. m.

The meeting will be held under the auspices of the Electrophysics Committee, which has arranged for the presentation of two papers, *Air as an Insulator when in the Presence of Insulating Bodies of Higher Specific Inductive Capacity*, by C. L. Fortescue and S. W. Farnsworth, and *The Application of a Theorem of Electrostatics to Insulation Problems*, by C. Fortescue.

At the close of the technical session in the auditorium the meeting will adjourn to the Institute offices on the 10th floor, where the usual smoker will be held and light refreshments served.

A. I. E. E. Lectures on Radioactivity

It has been found necessary to change the dates for the series of lectures on "Radioactivity" to be given by Professor Edwin P. Adams of the Palmer Physical Laboratory of Princeton University, under the auspices of the Electrophysics Committee of the Institute, of which preliminary announcement was made in the February PROCEEDINGS. The lectures will be given at 8:15 p.m. on Wednesday evenings, March 19 and 26, and April 2 and 9, in the auditorium of the Engineering Societies Building, 33 West 39th Street, New York.

Following is an outline of the topics to be treated in the four lectures:

LECTURE I—MARCH 19

The discovery of the property of radioactivity.

Radium and its preparation.

Ionization of gases.

Nature of the radiations from radioactive substances—alpha, beta and gamma rays.

LECTURE II—MARCH 26

The disintegration theory of radioactivity.

The distribution of radioactive substances.

Radium and the age of the earth.

LECTURE III—APRIL 2

Dependence of the mass of an electron on its velocity.

The electron theory of matter.

Electrons in optical theory. Zeeman effect.

Emission and absorption of light.

LECTURE IV—APRIL 9

Metallic conduction.

Indication afforded by the study of radioactivity regarding the structure of the atom.

Optical phenomena in moving bodies.

The principle of relativity.

Meeting at Pittsburgh, April 18-19, 1913

The Board of Directors has authorized the holding of a two-day meeting of the Institute in Pittsburgh, Pa., April 18-19. This meeting is to be held under the auspices of the Institute's Committee on the Use of Electricity in Mines, in co-operation with the Pittsburgh Section. The Institute headquarters during the meeting will be at the Fort Pitt Hotel, where the sessions will be held.

Further notice of the program for the meeting will be given in the April PROCEEDINGS.

Annual Convention, Cooperstown, N. Y., June 23-27, 1913

At the meeting of the Board of Directors held on February 14, it was decided to hold the 1913 Annual Convention of the Institute at Cooperstown, N. Y., during the week beginning Monday, June 23. The Hotel Otesaga has been selected as the convention headquarters.

The Meetings and Papers Committee is arranging an interesting technical program. All papers intended for presentation at the convention should be received at Institute headquarters by April 1 in order to insure their publication in the PROCEEDINGS sufficiently in advance of the convention to afford ample time for the preparation of discussion.

Further details regarding arrangements for the convention will be published in coming issues of the PROCEEDINGS.

Pacific Coast Convention, September 9—11, 1913

At the request of the Institute members in Vancouver and vicinity, the Board of Directors has authorized the holding of the annual Pacific Coast Convention of the A. I. E. E. at Vancouver, British Columbia, on September 9, 10 and 11, 1913. The Vancouver Section has been working for some time in preparation for this convention, and has already arranged for a number of papers, and plans are maturing for interesting trips to some of the large hydroelectric installations in the vicinity of Vancouver. Arrangements are being made for special rates over all railroads, and as this will afford to the engineering fraternity an excellent opportunity for visiting this region so interesting from the point of view of hydroelectric development, it is expected that a large attendance from the East, as well as from the West, will be assured.

International Electrotechnical Commission

The following statement regarding the work of the International Electrotechnical Commission has been received from General Secretary C. le Maistre:

" The meetings of the special committees of the I. E. C., held recently in Zurich, have resulted in considerable practical progress.

" The meetings, which occupied eight days, were held in the Town Hall and were presided over by Professor Dr. W. Wyssling (Symbols), Mr. E. Huber-Stockar (Rating), Dr. H. Zoelly (Prime Movers).

" Probably the most difficult subject discussed was that of symbols, but if the national committees will take steps to insure the adoption of the proposals, after ratification at Berlin in September next, good will result, for, though the suggestions are not extensive, their employment by writers generally will result in a considerable amount of unification which at present does not exist. Professor Miles Walker's suggestions for starting *de novo* and adopting an entirely new method of dealing with the subject were given due consideration; the delegates, however, felt unanimously that such a procedure was impossible.

" Considerable discussion took place as to the relative importance of distinguishing between vector and scalar quantities as against electric and magnetic, some delegates regretting that for the sake of a comparatively small number of magnetic quantities the entire alphabet of script characters was unavailable for vector quantities which, in their opinion, would be bound to be employed to an increasing extent by electricians in the practical solution of their many problems.

" We understand that in Germany the time has apparently arrived when it is of great importance to distinguish between vector and scalar quantities. No doubt, therefore, before the Berlin meeting this important matter will be discussed very fully, and indeed there is a growing feeling that this proposal emanating from the German A. E. F. merits more consideration by the national committees than has hitherto been accorded it.

" The special committee on Symbols wisely made certain modifications in its list of symbols so that, should the German view find favor ultimately and script letters not be recommended for magnetic quantities, no confusion would occur by two identical letters being proposed for the same quantity whether magnetic or electric.

" The Rating of Electrical Machinery occupied three whole days and though the discussions were long and arduous they were of the most cordial character. The American views were ably put forward by Mr. C. O. Mailloux, who drew the attention of the delegates to the Midwinter Convention of the A.I.E.E., inviting them specially to be present if the distance and their own engagements did not prevent it.

" Dr. Kapp, the British representative, was assisted by the official representative of the British Electrical and Allied Manufacturers Association, Mr. A. R. Everest.

" Modifications and new proposals had been received from many of the national committees and their consideration has rendered the present proposals more complete and certainly far more likely of acceptance by the industry generally than were the Paris proposals of last March; it must, however, be remembered that at Paris no concrete proposals were before the committee. The proposed international standard for copper was only briefly discussed, as Dr. Glazebrook and Professor Paul Janet kindly consented to consult with the other national laboratories on the subject and transmit their final decision to the Central Office for submission to the Berlin Meeting of the I. E. C.

" The special committee on Prime Movers has, after detailed discussion and modification, adopted the report prepared by the Italian Committee, as the result of two years' work on hydraulic-electrical installations. The question of steam engines in connection with electrical plant will next engage its attention. An important proposal was unanimously adopted, ' that the industrial unit of mechanical power be the kilowatt.' It is therefore hoped that the German society, the A. E. F., will consent to withdraw the proposal to call the mechanical kilowatt the ' neupferd ', which, it is understood, is only a tentative one.

" Detailed reports of the work of these special committees will be issued by the Central Office of the I. E. C. without delay, and it should be noted that the proposals of these committees are to be submitted for the consideration of the various national committees with a view to their ratification at the next plenary meeting of the Commission which, through the kindness of the Germans, will be held in Berlin from the 2nd to the 6th of September next.

" It is interesting to note that the Italian Society of Electricians has decided to adopt the recommendations of the I. E. C. as and when promulgated and to recommend their employment in all international specifications for electrical machinery. They have also decided to suggest that, when the necessity arises, in international contracts, for an arbitrator, he shall be chosen by the president, for the time being, of the I. E. C.

" In conclusion, the general arrangements for the comfort and entertainment of the twenty-five delegates were admirably attended to by the Swiss

Committee and the Swiss Society of Electricians, the president of which society, Professor Jean Landry, came from Lausanne to preside at the official banquet.

"The wisdom of the Turin Meeting in appointing these small international special committees to discuss actual details and formulate definite proposals has amply justified itself. The work of the Zurich meetings will undoubtedly be of real practical value to the industry, for when finally adopted at Berlin, the Zurich proposals will form the foundation of international specifications for use by the electrical industry of all nations."

Directors' Meeting, February 14, 1913

The Board of Directors of the American Institute of Electrical Engineers held its regular monthly meeting at Institute headquarters on Friday, February 14, 1913, at 3:30 p.m.

Present: Past-President Gano Dunn, New York; Vice-Presidents Charles W. Stone, Schenectady, N. Y., A. W. Berresford, Milwaukee, Wis., S. D. Sprong, Brooklyn, N. Y.; Managers W. S. Rugg, Charles E. Scribner and William McClellan, New York, Farley Osgood, Newark, N. J., Comfort A. Adams, Cambridge, Mass., and J. Franklin Stevens, Philadelphia, Pa.; Treasurer George A. Hamilton, Elizabeth, N. J., and Secretary F. L. Hutchinson, New York.

In the absence of President Mershon, who was then on the Pacific coast, Vice-President Charles W. Stone presided.

Monthly bills amounting to $12,615.59 were approved.

The Meetings and Papers Committee submitted a list of places suitable for holding the Annual Convention of 1913. The Board voted unanimously to hold the Convention in Cooperstown, N. Y., during the week beginning Monday, June 23, 1913.

The Board authorized a two-day Institute meeting in Pittsburgh, Pa., during the latter part of April, under the auspices of the Committee on the Use of Electricity in Mines, in co-operation with the Pittsburgh Section. The exact date of the meeting was left to the discretion of the Meetings and Papers Committee.

In view of the unusual activity incidental to the holding of the midwinter convention in New York, February 26-28, 1913, and the lectures on radioactivity to be given under the auspices of the Institute's Electrophysics Committee on Wednesday evenings, March 19 and 26, and April 2 and 9, it was voted to omit the April New York meeting, so that the regular meeting scheduled for Friday, April 11, will not be held.

The lectures on radioactivity had previously been announced for Tuesday evenings during the latter part of March and April, but upon recommendation of the Meetings and Papers and Electrophysics Committees the dates were changed to Wednesday evenings, March 19, 26, April 2 and 9.

The report of the Board of Examiners of its meeting held on January 31 was read and the action taken by the Board at that meeting was approved.

Upon recommendation of the Board of Examiners 101 Associates were elected, and 80 students were ordered enrolled.

The following applicants were elected directly to the grade of Member: Andrew Kidd, Jr., New York; Herbert Nash, Jr., Boston, Mass.; George Weston, Chicago, Ill.

The following applicants were transferred to the grades of Member and Fellow, under the regular provisions of the Constitution:

To the grade of Member: Lawrence Birks, Wellington, New Zealand.

To the grade of Fellow: Nevil M. Hopkins, Washington, D. C.; W. C. Lancaster, Montreal, P.Q.; Frederick L. Rhodes, New York.

The special committee appointed by the Board at its January meeting to examine applications for transfer to the grades of Member and Fellow under the special section of the Constitution reported having individually examined 79 applications for transfer from the grade of Member to that of Fellow, and 116 applications for transfer from the grade of Associate to that of Member, all of which had been found to comply with the requirements of the special section.

On motion all of these 79 and 116 applicants were transferred to the grades of Fellow and Member, respectively.

Upon the recommendation of the Sections Committee, the organization of a Section was authorized at Spokane, Washington, in response to a petition signed by 25 Members and Associates residing in that territory.

Letters were read from the Verband Deutscher Elektrotechniker, of Germany, and the Koninklijk Instituut van Ingenieurs, of Holland, concurring in the plan proposed by the Institute last year for the exchange of visiting member privileges.

Report of Special Committee on Past President's Testimonial

In the course of the conference of Section delegates held during the Boston Convention last June, a resolution was passed recommending to the Board of Directors that a sum be set aside each year to purchase, for presentation to the outgoing president, a suitable testimonial which could be retained as an expression of the appreciation on the part of the American Institute of Electrical Engineers of his services to the Institute. The resolution came before the Board of Directors at a special meeting held during the convention, and as a result of this recommendation the Board authorized the appointment of a committee to consider and report on this question. President Dunn, with the concurrence of President-elect Mershon, appointed Messrs. W. S. Rugg, chairman, Severn D. Sprong, and W. G. Carlton, members of this special committee.

The committee, after thoroughly considering the matter, submitted the following report to the Board of Directors at the meeting held on February 14, 1913, which was approved by the Board and ordered published in the PROCEEDINGS.

"The committee has carefully considered this matter and believes that the subject is a broader one than would at first appear, in that it affects an action of the Board of Directors taken at the time when the original committee on Past Presidents' Badge was appointed.

"This latter committee was appointed in response to a very general sentiment that the past presidents should receive some distinctive testimonial of the position which they had occupied, which testimonial should be of such a nature that it would be at once dignified and suitable for everyday use. The resolution at that time defined this testimonial as the Past Presidents' Badge and the committee determined its form.

"This was gone into thoroughly; various alternatives were suggested and the sentiment of quite a number of past presidents was obtained. Based upon this very painstaking consideration by such committee, the committee made certain suggestions which later took the form of the Past Presidents' Badge, as we now know it. These suggestions were unanimously endorsed by the committee and submitted to the Board with its report, which was appoved by the Board.

"The presentation of these badges to the past presidents was made a special feature of the Institute Reception held at New York, February 28, 1911, at which nearly all of the past presidents were present.

"In view of the history of the past presidents' badge as briefly given above, it is the opinion of your committee that such badge still fulfills the intentions as expressed by the Board of Directors and is acceptable to the past presidents. It expresses in a dignified form the sentiment of the Institute for them, which sentiment obviously cannot be measured by the intrinsic value of the testimonial; in fact, many difficulties would, in the opinion of your committee, attend the giving of a testimonial having any considerable intrinsic value.

"In arriving at the above conclusion, the committee appreciates fully the sentiment toward our past presidents, which prompted the resolution, and it is believed that this sentiment, which is, of course, general throughout the Institute, is very adequately expressed by the present badge. The committee is confirmed in its judgment of this matter through the fact that they have been unable to find any essential point of view which was overlooked by the original committee.

"The committee, therefore, recommends that no change be made in the manner and means of expressing to the past presidents the regard and appreciation of the Institute for their activities."

THE FORUM

Dedicated to the Discussion of Institute Affairs

To the membership of the A. I. E. E.:

In the January number of the PROCEEDINGS of the American Institute of Electrical Engineers is published a list of members transferred to the new grade of " Fellow " by vote of the Board of Directors on December 13, 1912.

Under the heading " Recommended for Transfer by the Board of Examiners" appears one name. Under the heading " Transferred in accordance with the Special Section of the Constitution " appear 88 names.

At the same meeting, 89 Associates were transferred to the grade of " Member " in accordance with the special section of the constitution.

The single individual is a past president of the Institute, and a man of the highest standing, and that he was transferred through the regular course of procedure, and not under the provisions of the special section, is significant. Apparently he took this means of protesting, in the only manner open to him, against the " Special Section " of the constitution, which was adopted at the time the grade of Fellow was created.

This special section makes mandatory the transfer to the grade of " Fellow " of any " Member " who shall make request to the secretary prior to May 1, 1913, for transfer, and who refers to five " Members " or " Fellows " who shall certify that he meets the requirements of the grade of Fellow.

It also makes mandatory the transfer of any " Associate " to the grade of " Member " on compliance with the same routine, except that his references shall be four " Fellows " or " Members."

The captions of the published lists indicate that in cases of applications for transfer under the special section, no scrutiny or supervision is allowed to the Board of Examiners, the regularly constituted channel through which all applications for transfer have gone in the past and will go in the future.

It is certainly unfortunate that any such exception to the regular provisions and procedure was ever passed.

It may be argued that the references given take the place of the Board of Examiners, but they cannot be considered as equivalents.

The members of the Board of Examiners have in the past been men free from connections through which direct or indirect influence might be used to control their action in any given case, and " Fellows " or " Members " who carry the approval of and who have been transferred by recommendation of the Board of Examiners will, at least in some eyes, be regarded as more certainly meeting the requirements of the grades of " Fellow " and " Member," than those who have been transferred under the perfunctory procedure of the special section.

At any rate, I believe that their names should appear in the Institute lists in such a way that it can be told at a glance in what way they have attained the grade they hold.

I believe that Members and Associates, other than the one above mentioned, who have applied for transfer would not have done so under the special section, had the matter been put up to them from the point of view expressed herein, and I hope that what I have said may influence some who have not yet applied.

A. M. HUNT.

San Francisco, Cal.
February 13, 1913.

United Engineering Society Treasurer's Report

To the Board of Trustees,
United Engineering Society:

I beg to submit herewith the report of your Treasurer as of December 31, 1912.

I. Finances

The balance sheet submitted herewith shows the physical property of the United Engineering Society, over and above the value of building and the equity in the land, to consist of building equipment of a value of $26,624.72, furniture and fixtures $6,005, and library books $329.07.

There was added to the furniture and fixtures account during the year 1912 an amount representing an expenditure of $1,383.77, including oak desk, table and chairs in library, also four large oak tables and twenty-four chairs to be used in the assembly rooms, safe for superintendent's office, and two Edison business phonographs. In accordance with a resolution of the Board of Trustees, 10 per cent depreciation was charged off this account for the year 1912.

The principal of the mortgage on the land held by Andrew Carnegie Esq., amounting originally to $540,000, has been reduced by payments from the Land and Building Funds of the Founder Societies to $128,000. There have been no further payments made during the year by the founder societies and the balances due from the societies remain the same as last year, namely, American Institute of Electrical Engineers $54,000, and American Institute of Mining Engineers $74,000. The American Society of Mechanical Engineers has paid the full amount of its indebtedness.

The gross operating expenses for the year 1912 were $47,602.71, an increase over the year 1911 of $9,323.56, which is accounted for by the following unusual expenditure authorized in the Minutes of the Board of Trustees—the expenditure for improving ventilating system in auditorium; storm windows fifth floor; interior painting, driveway repairs, iron fence, storm door Western entrance, and re-equipping 101 thermostats (including an augmented payroll of $548.66) amounted to $7,910.96 the main item being $4,562.50 expended on ventilating system. An additional sum of $2,034.75 was expended in alterations, which was reimbursed by the different societies for whom the changes were made.

In accordance with a resolution of the Board at a meeting held on January 25, 1912, an appropriation of $5,000 was made out of the surplus for the year 1911, and of this amount $4,755 was invested in $6,000 Southern Railway Development and General Mortgage Four Per Cent Bonds, due 1956, at 79¼, as an addition to the Contingency and Renewal Fund, as provided for in the Founders' Agreement, bringing the invested amount of the Reserve Fund up to $25,020. It is recommended that a similar appropriation be made out of the available balance from this year's operations, which will then show a balance to be added to surplus account of $952.19.

The assessments paid for the year by the founder societies, each occupying an entire floor, were $3,375 (against $4,500 each for the year 1911), representing a total expenditure by each founder society, including interest on its full principal of mortgage on land, of $10,575, reduced in each case to the extent the society may have paid off part or all of its mortgage share. The associate societies are assessed approximately $10,000 for equivalent facilities, which shows that the founder societies still meet a little more than their proportion of the carrying charges for equivalent office space occupancy in the building.

II. Building

Equipment: The real estate equipment account during the year 1912 has been increased to an extent of

$1,587, expended mainly in needed electrical work in the library.

Office Occupancy: There was on January 1, 1913, no unoccupied floor space devoted to office use in the building. There are, however, two rooms on the twelfth floor formerly used for storage purposes and now temporarily used by the library, from which no income has been received during the year.

Meetings or Lectures: The record of the number of times the rooms were used during 1912 for meetings or lectures (not for office occupancy) is shown in the accompanying table.

MEETINGS IN ENGINEERING SOCIETIES BUILDING DURING 1912.

Meeting Room	Number of times occupied		
	1911	1912	Change
Auditorium 3rd and 4th floors	44	46	2 more
No. 1 Assembly Room 5th floor	40	39	1 less
" 2 " " 5th "	54	70	16 more
" 3 " " 5th "	10	33	23 "
Lecture Room No. 5 6th "	34	35	1 "
" " " 6 6th "	7	0*	7 less
" " " 8 6th "	86	84	2 "
Small Committee Room 7th "	26	12*	14 "
Total	301	319	18 more

*No. 6 Lecture Room is now occupied by the American Museum of Safety, and the small Committee Room as an office by the Aeronautical Society.

During the year 1912 the facilities of the building were enjoyed by 60 societies holding a total of 253 meetings, with an attendance of 42,324, as contrasted with 251 meetings during 1911, with an attendance of 42,400.

III. LIBRARY

During the year 1912 there were added to the Library of the three Founder Societies and United Engineering Society, 3183 volumes and pamphlets, of which 1103 volumes and pamphlets were purchased at a cost of $3,819.16. The total number of books and pamphlets in the library at the end of the year is 50,683.

The attendance during the year was 10,522 as compared with 11,014 during 1911—a slight decrease.

The department of research work has been developed as far as the present force will permit. Searches to the number of 160 have been made on a great variety of subjects in answer to requests received from correspondents in Japan, South Africa, Mexico, Canada and England, as well as from different parts of the United States, including several hundred photographic reproductions.

The Library receives more than 700 technical periodicals, which are available through indexes for research purposes.

Respectfully submitted,
J. STRUTHERS
Treasurer.

Addresses Wanted

Name	Former address
S. B. Mambert,	288 Broadway, Kingston, N. Y.
Meinig Rud,	494 Fourth St., Beaver, Pa.
Raymond Whiteley,	Antofagasta, Chile, S. A.

Anyone who can give information that may assist in obtaining any of these addresses is requested to communicate with the secretary of the Institute.

Recommended for Transfer to Grade of Fellow, January 31, 1913

The following members were recommended for transfer to the grade of Fellow by the Board of Examiners at its regular monthly meeting held on January 31, 1913. Any objection to these transfers should be filed at once with the Secretary:

Lawrence Lee Gaillard, Vice-President and General Manager, New England Engineering Co., New York, N. Y.

Henry Graftio, Ministry of Ways of Communication, St. Petersburg, Russia.

Harry N. Latey, Electrical Engineer with General Electric Co., New York, N. Y.

Transferred to Grade of Fellow, February 14, 1913

The following were transferred to the grade of Fellow of the Institute at the meeting of the Board of Directors on February 14, 1913.

RECOMMENDED FOR TRANSFER BY THE BOARD OF EXAMINERS

Hopkins, Nevil Monroe, Consulting Electrical Engineer, Washington, D. C.

Lancaster, W. C., Electrical and Mechanical Engineer, Canadian Northern Tunnel and Terminal, Montreal, Que.

Rhodes, Frederick L., Outside Plant Engineer, American Tel. & Tel. Co., New York, N. Y.

TRANSFERRED IN ACCORDANCE WITH THE SPECIAL SECTION OF THE CONSTITUTION

Abbott, W. L., Chief Operating Engineer, Commonwealth Edison Co., Chicago Ill.

Adams, Comfort A., Professor of Electrical Engineering, Harvard University, Cambridge, Mass.

Berg, Ernst J., Professor of Electrical Engineering, University of Illinois, Urbana, Ill.

Bijur, Joseph, Manager, Bijur Motor Lighting Co., New York, N. Y.

Blood, W. H., Jr., Expert Engineering, Stone & Webster, Boston, Mass.

Brooks, Morgan, Professor of Electrical Engineering, University of Illinois, Urbana, Ill.

Burke, James, President, Burke Electric Co., Erie, Pa.

Campbell, W. Lee, General Superintendent, Automatic Electric Co., Chicago, Ill.

Carle, N. A., Chief Engineer, Public Service Electric Co., Newark, N. J.

Carty, John J., Chief Engineer, American Telephone & Telegraph Co., New York, N. Y.

Chace, William G., Member, Smith, Kerry and Chace, Toronto, Ont.

Chesney, C. C., Manager and Chief Engineer, General Electric Co., Pittsfield, Mass.

Cheyney, Algernon R., Superintendent of Operation, Philadelphia Electric Co., Philadelphia, Pa.

Clifford, H. E., Gordon McKay Professor of Electrical Engineering, Harvard University, Cambridge, Mass.

Cox, Frank P., Chief Meter Engineer, General Electric Co., Lynn, Mass.

Dow, Alex, Vice-President and General Manager, Edison Illuminating, Co., Detroit, Mich.

Field, A. B., Engineer, Westinghouse Electric & Mfg. Co., Pittsburgh, Pa.

Fish, F. A., Professor of Electrical Engineering, Iowa State College, Ames, Iowa.

Franklin, W. S., Professor of Physics, Lehigh University, South Bethlehem, Pa.

Freedman, W. H., Head of Department of Applied Electricity, Pratt Institure, Brooklyn, N. Y.

Garfield, A. S., Chief Engineer, Compagnie Francaise Thomson-Houston, Paris, France.

Gerry, M. H., Jr., President, International Power & Manufacturing Co., Helena, Mont.

Gossler, P. G., Management and Financing Public Utilities, A. B. Leach & Co., New York, N. Y.

Hadaway, W. S., Jr., Electric Heating Engineer, Cutler-Hammer Mfg. Co., New York, N. Y.

Hamilton, George A., Retired, Elizabeth, N. J.

Hanchett, George T., Consulting Electrical Engineer, New York, N.Y.

Hanssen, I. E., Consulting Engineer, Kristiania, Norway.

Harper, H. R., City Electrical Engineer, Melbourne, Aus.

Heitmann, Edward, Chief Engineer, Canadian Crocker-Wheeler Co., St. Catharines, Ont.

Hornor, H. A., Electrical Engineer, New York Shipbuilding Co., Philadelphia, Pa.

Howes, Robert, Consulting Engineer, Seattle, Wash.

Hoxie, George L., Consulting Engineer, Hoxie and Goodloe, New York, N. Y.

Humphrey, Henry H., Consulting Electrical and Mechanical Engineer, St. Louis, Mo.

Hunting, F. S., General Manager, Fort Wayne Electric Works, Fort Wayne, Ind.

Jackson, William B., Consulting Engineer, Chicago, Ill.

Kirker, Harry L., Railway Electrification, Westinghouse Electric & Mfg. Co., Pittsburgh, Pa.

Lacombe, Charles F., Chief Engineer of Light and Power, Dept. of Water Supply, Gas and Electricity, New York, N. Y.

Lanphier, Robert C., Secretary and General Manager, Sangamo Electric Co., Springfield, Ill.

Lemp, Hermann, Jr., Electrical Engineer, General Electric Co., Erie, Pa.

Lighthipe, James A., Electrical Engineer, Southern California Edison Co., Los Angeles, Cal.

Lyman, James, Member of Firm, Sargent & Lundy, Chicago, Ill.

Magnusson, C. Edward, Professor of Electrical Engineering, University of Washington, Seattle, Wash.

Marburg, L. C., Secretary-Treasurer and Chief Engineer, Marburg Brothers, Inc., New York, N. Y.

Marks, Louis B., Consulting Engineer, New York, N. Y.

McCormick, Bradley T., Chief Electrical Engineer, Allis-Chalmers-Bullock, Ltd., Montreal, Can.

McCoy, Walter E., Electrical Engineer, United Electric Light & Power Co., New York, N. Y.

McKay, C. R., General Manager, Union Light, Heat & Power Co., and South Covington & Cincinnati St. Ry. Co., Covington, Ky.

Meredith, Wynn, Member of Firm, Sanderson and Porter, San Francisco, Cal.

Miller, Decatur S., Supervisor, Elec. Gen. and Distribution, The Connecticut Co., New Haven, Conn.

Miller, J. Edgar, Engineer, J. G. White & Co., New York, N. Y.

Mosman, Charles T., **District** Engineer, General Electric Co., Boston, Mass.

Nicholson, S. L., Sales Manager, Westinghouse Electric & Mfg. Co., Pittsburgh, Pa.

Parshall, Horace F., Consulting Engineer, London, E. C., England.

Peck, Henry W., Vice-President and General Manager, Schenectady Illuminating Co., Schenectady, N. Y.

Phillips, Leo A., Special Engineer, Allis-Chalmers Co., Milwaukee, Wis.

Pikler, Armin H., Engineer, In charge Transformer Department, Crocker-Wheeler Co., Ampere, N. J.

Reno, C. S., Manager, Expanded Metal Eng. Co., President, Reno-Kaetker Elec. Co., New York, N. Y.

Rhodes, Samuel G., Engineer, Meter and Test Depts., New York Edison Co., New York, N. Y.

Riggs, W. M., President and Consulting Professor of Engineering, Clemson Agricultural College, Clemson College, S. C.

Rowe, Bertrand P., Electrical Engineer, Westinghouse Electric & Mfg. Co., Pittsburgh, Pa.

SAWYER, W. H., Electrical Engineer, Ford, Bacon and Davis, New York, N. Y.

SCHILDHAUER, EDWARD, Electrical and Mechanical Engineer, Culebra, C. Z.

SCHOEPF, T. H., General Engineer, Westinghouse Electric & Mfg. Co., Pittsburgh, Pa.

SCRIBNER, CHARLES E., Chief Engineer, Western Electric Co., New York, N.Y.

SESSIONS, E. O., Consulting Engineer, Chicago, Ill.

SHELDON, S. R., Dean and Professor of Electrical Engineering, Nanyang University, Shanghai, China.

SIMMONS, B. F., Steam and Electric Engineer, Holyoke Water Power Co., Holyoke Mass.

SIMON, ARTHUR, Electrical Engineer, Cutler-Hammer Mfg. Co., Milwaukee, Wis.

STEBBINS, THEODORE, Public Utilities Expert, New York, N. Y.

STEVENS, J. **FRANKLIN**, Consulting Electrical Engineer, Philadelphia, Pa.

STORER, N. W., General Engineer, Railway Dept., Westinghouse Electric & Mfg. Co., Pittsburgh, Pa.

STUART, HARVE R., Designing Engineer, Robbins & Myers Co., Springfield, Ohio.

SUNNY, BERNARD E., President, Chicago Telephone Co., Chicago, Ill.

THOMPSON, WILBUR H., Electrical Engineer, Westinghouse Electric & Mfg. Co., Pittsburgh, Pa.

TURNER, WILLIAM S., Consulting Engineer, Portland, Ore.

WARREN, HOWARD S., Electrical Engineer, American Tel. & Tel. Co., New York, N. Y.

WILSON, H. S., Commercial Electrical Engineer, New England Engineering Co., Waterbury, Conn.

WOODMANSEE, FAY, Consulting Engineer, Chicago, Ill.

YOUNG, C. **GRIFFITH**, Engineering Construction and Examinations, New York, N. Y.

Total. 82

Transferred to Grade of Member, February 14, 1913

The following Associates were transferred to the grade of Member of the Institute at the meeting of the Board of Directors on February 14, 1913.

RECOMMENDED FOR TRANSFER BY THE BOARD OF EXAMINERS

BIRKS, LAWRENCE, Electrical Engineer, Public Works Department, Wellington, N. Z.

TRANSFERRED IN ACCORDANCE WITH THE SPECIAL SECTION OF THE CONSTITUTION

ABBOTT, ARTHUR L., Manager, Electric Construction Co., St. Paul, Minn.

ALLEN, CLAXTON E., Assistant Manager Detail & Supply Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

ALLEN, OLIVER F., Sales Engineer, Fort Wayne Dept., General Electric Co., New York City.

ALLENSWORTH, HARRY R., Superintendent, Fire & Police Teleg., Columbus, Ohio.

ALVERSON, HARRY B., Superintendent, Cataract Power & Conduit Co., Buffalo, N. Y.

BARD, J. W., Electrical Engineer, Sangamo Elec. Co., Springfield, Ill.

BATES, CLIFFORD W., Instructor in Electrical Engineering, Sheffield Scientific School, New Haven, Conn.

BAUM, WILLIAM, Berlin Representative, General Electric Co., Berlin, Germany.

BRIGHT, GRAHAM, Electrical Engineer, Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

BROOKS, LOUIS C., Industrial Control Eng. Dept., General Electric Co., Schenectady, N. Y.

BRYANT, J. M., Assistant Professor of Electrical Engineering, University of Illinois, Urbana, Ill.

CHENEY, EDWARD J., Electrical Engineer, General Electric Co., Schenectady, N. Y.

COATES, CHARLES B., Manager Electrical Dept., Chicago Pneumatic Tool Co., Chicago, Ill.

Coey, Stewart C., Assistant Superintendent of Electrical and Mechanical Depts., Youngstown Sheet & Tube Co., Youngstown, O.

Cook, A. L., Engineer, Westinghouse, Church, Kerr & Co., New York, N. Y.

Cope, A. N., President, Capitol Engineering Co., Columbus, O.

Corbett, L. J., Associate Professor (in charge) of Electrical Engineering, University of Idaho, Moscow, Idaho.

Cravath, James R., Electrical & Illuminating Engineer & Central Station Manager, Chicago, Ill.

Crosse, Shirley R., Chief Inspector, Stone & Webster Engineering Corp., Boston, Mass.

Dawson, William F., Designing Engineer, General Electric Co., Lynn, Mass.

Deakin, Gerald, Engineer of Automatic Plants, Pacific Tel. & Tel. Co., San Francisco, Cal.

De Remer, J. G., Chief Engineer, United Light & Power Co., San Francisco, Cal.

Dixon, James, Superintendent Construction Crocker Wheeler Co., Ampere, N. J.

Eliot, Edward M., Assistant Engineer, Texas Power & Light Co., Dallas, Tex.

Fairchild, A. Royal, Electrical Engineer, Tennesee Eastern Electric Co. and Tennessee Natural Development Co., Greeneville, Tenn.

Fenner, Robert C., Manager Chicago Office, Cutler-Hammer Mfg. Co., Chicago, Ill.

Flowers, Alan E., Professor of Electrical Engineering, Ohio State University, Columbus, Ohio.

Foote, E. T., Engineer, Cutler-Hammer Mfg. Co., Milwaukee, Wis.

Frank, John J., Trans. Designing Engineer, General Electric Co., Pittsfield, Mass.

Frankenberg, John T., Chief Engineer, Providence Telephone Co., Providence, R. I.

Franz, Joseph, Engineer, Rogers Electric Co., Lee, Mass.

Freeman, Ernest H., Professor of Electrical Engineering, Armour Institute of Technology, Chicago, Ill.

Freudenberger, W. K., Chief Engineer, Public Service and Railroad Commissions of Nevada, Carson City, Nev.

Funk, N. E., Assistant Superintendent of Operation, Philadelphia Electric Co., Philadelphia, Pa.

Gay, Frazer W., Chief Tester, Crocker-Wheeler Co., Ampere, N. J.

Gaylord, James M., Engineer, U. S. Reclamation Service, Los Angeles, Cal.

Gear, Harry B., Engineer of Distribution, Commonwealth Edison Co., Chicago, Ill.

Goettsch, Julius, Assistant General Superintendent, D. H. Burnham & Co., Chicago, Ill.

Goldenstein, Maurice M., Electrical Engineer, Cutler-Hammer Mfg. Co., Milwaukee, Wis.

Graef, Walter H., Electrical Engineer, F. H. Walter & Co., Rio de Janeiro, Brazil.

Graham, E. A., Assistant Electrical Engineer, Winnipeg Electric Ry. Co., Winnipeg, Man.

Graham, William P., Professor of Electrical Engineering, Dean, College of Applied Science, Syracuse, N. Y.

Gray, Clyde D., Assistant Electrical Engineer, J. G. White & Co., New York, N. Y.

Haar, Selby, Electrical Engineer, Siemens-Schuckert Co., New York, N. Y.

Hall, F. A., Assistant Electrical Engineer, Turbine Dept., General Electric Co., Lynn, Mass.

Hanker, Fred C., General Engineer, Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

Hansell, C. E., Sales Engineer, Esterline Co., West Lafayette, Ind.

Harrelson, Allen M., Chief Electrical Engineer, Emerson Elec. Mfg. Co., St. Louis, Mo.

Harris, F. W., Consulting Engineer, Los Angeles, Cal.

Harvey, A. L., Electrical Engineer, Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

Hawkins, Laurence A., Electrical Engineer of the Research Laboratory, General Electric Co., Schenectady.

Hays, John C., President & Consulting Engineer, Mt. Whitney Power & Electric Co., Visalia, Cal.

Henkhe, Edmund, Textbook Writer on Electrical Engineering, International Correspondence School, Scranton, Pa.

Hillebrand, W. A., Professor of Electrical Engineering, Oregon Agricultural College, Corvallis, Ore.

Israel, Joseph D., District Manager, Philadelphia Electric Co., Philadelphia, Pa.

Jenista, George J., Director of Engineering Courses & Professor of Electrical Engineering, De Paul University, Chicago, Ill.

Kinsloe, Charles L., Professor of Electrical Engineering, Pennsylvania State College, State College, Pa.

Lebenbaum, Paul, Electrical Engineer, Portland, Eugene & Eastern Ry. Co.; Portland, Ore.

Lichtenberg, Chester, Electrical Engineer, General Electric Co., Schenectady, N. Y.

Lindberg, F. A., Member of firm, Brill & Gardner, Chicago, Ill.

Loew, Edgar A., Assistant Professor of Electrical Engineering, University of Washington, Seattle, Wash.

MacDowell, A. S., Electrical Engineer, Station Construction, Rochester Railway & Light Co., Rochester, N. Y.

Maclachlan, Wills, Local Manager, Trenton Electric & Water Co., Belleville, Ont.

Macomber, Alexander, Electrical Engineer, C. H. Tenney & Co., Boston, Mass.

Magraw, L. A., Manager & Chief Engineer, Central Georgia Power Co., Macon, Ga.

Mahood, David, Jr., Chief Subinspector, Electrical, Navy Yard, New York, N. Y.

Marca-Romero, M. A., Government Engineer, Lima, Peru.

Meyer, Edward B., Assistant to Chief Engineer, Public Service Elec. Co., Newark, N. J.

Milton, Taliaferro, District Engineer, Electric Storage Battery Co., Chicago, Ill.

Mitchell, W. G., Manufacturing Engineer, General Electric Co., Lynn, Mass.

Montignani, John O., Engineer, Electrical Distribution, Rochester Railway & Light Co., Rochester, N. Y.

Morris, Robert, Inspector, N. Y. C. & H. R.R. R. Co., New York, N. Y.

Mountain, J. T., Assistant to Chief Operating Engineer, Commonwealth Edison Co., Chicago, Ill.

Muller, Ernest W., Professional Electrical Engineer, Mailloux & Knox, New York, N. Y.

Norton, William J., Special Electric Rate Work, Commonwealth Edison Co., Chicago, Ill.

Offutt, M. Webb, Alabama Interstate Power Co.; Alabama Power Co., Birmingham, Ala.

Owen, Llewellyn, Superintendent, Electric Dept., Peoria Gas and Electric Co., Peoria, Ill.

Pattison, R. S., Commercial Engineer, Emerson Electric Mfg. Co., St. Louis, Mo.

Pfund, Richard, Engineer and General Manager, Telefunken Wireless Telegraph Co.of the U. S.,New York, N. Y.

Phillips, Thomas Lodge, Construction Engineer, Pacific Light & Power Corp., Los Angeles, Cal.

Plaisted, Arthur I., Electrical Engineer, Metropolitan Park Commission, Boston, Mass.

Pollard, Nelson L., Electrical Engineer, Public Service Electric Co., Elizabeth, N. J.

Ramsey, J. C., Jr., Electrical Engineer, American Woolen Co., Laurence, Mass.

Read, Norman, Electrical Engineer and Supt. Motive Power, Denver City Tramway Co., Denver, Colo.

Reed, Henry A., President and General Manager, Bishop Gutta Percha Co., New York, N. Y.

REED, HENRY D., Vice-President, Bishop Gutta Percha Co., New York, N. Y.

RIPPLE, PAUL W., Chief Engineer Power and Equipment, The Connecticut Co., New Haven, Conn.

ROBBINS, CHARLES, Manager, Industrial and Power Dept., East Pittsburgh, Pa.

ROBBINS, H. A., Superintendent of Power, Brooklyn Rapid Transit System, Brooklyn, N. Y.

ROSOK, INGWALD A., Chief Electrician, Bisbee Improvement Co., Bisbee, Ariz.

RUGG, WALTER S., Manager, New York Office, Westinghouse Electric & Mfg. Co., New York, N. Y.

RYPINSKI, M. C., Manager Detail and Supply Div., Westinghouse Electric & Mfg. Co., New York, N. Y.

SANDS, HERBERT S., Manager, Industrial & Power Div., Westinghouse Electric & Mfg. Co., Denver, Colo.

SANFORD, GEORGE E., Electrical Engineer, General Electric Co., Lynn, Mass.

SANFORD, H. B., Professor of Electrical Engineering, Nanyang University, Shanghai, China.

SAWIN, G. A., Meter and Illuminating Engineer, Public Service Electric Co., Newark, N. J.

SCHICK, D. FREDERICK, Electrical Engineer, Philadelphia Electric Co., Philadelphia, Pa.

SCHNEIDER, C. A., Electrical Superintendent, The Connecticut Co., New Haven, Conn.

SHALLCROSS, W. M., Designing Engineer, Cutler-Hammer Mfg. Co., Milwaukee, Wis.

SHARER, CARL W., Supt. of Equipment Dept., Keystone Tel. Co., Philadelphia, Pa.

SMITH, IRVING W., Electrician, Bishop Gutta Percha C., New York, N. Y.

SOANS, C. A., Electrical Engineer, Bijur Motor Lighting Co., New York, N. Y.

STROBEL, H. J., Electrical Engineer, Stone & Webster Engg. Corpn., Boston, Mass.

TAUSSIG, WILLIAM S., General Electric Co., Chicago, Ill.

THORNTON, KENNETH B., Chief Engineer and Operating Manager, Canadian Light & Power Co., Montreal, Can.

UNDERWOOD, LOUIS E., General Electric Co., West Lynn, Mass.

VAN VLEET, R. M., Sales Engineer, Cutler-Hammer Mfg. Co.,Milwaukee, Wis.

WAGNER, WALTER C., Assistant Professor Electrical and Mechanical Engineering, Clemson Agricultural College, Clemson College, S. C.

WARREN, ALDRED K., Manufacturing Engineer, General Electric Co., West Lynn, Mass.

WATSON, JAMES T., Superintendent and Electrical Engineer, Municipal Electric Light Plant, Pulaski, Tenn.

WEED, J. MURRAY, Transformer Engineering Dept., General Electric Co., Pittsfield, Mass.

WHEELER, EARL, Local Manager, General Electric Co., Washington, D. C.

WILDER, EDWARD L., Industrial Engineer, Rochestei Railway & Light Co., Rochester, N. Y.

WALSER, ARTHUR, Sales Engineer, Fort Wayne Electric Works of G. E. Co., Fort Wayne, Ind.

WOODBRIDGE, J. LESTER, Chief Engineer, Electric Storage Battery Co., Philadelphia, Pa.

YERGER, CHARLES W., Engineer, Cutler Hammer Mfg. Co., Milwaukee, Wis.

Total 117.

Members Elected February 14, 1913

KIDD, ANDREW, Jr., Consulting Engineer, 95 Liberty Street; res., 535West 163rd St., New York, N. Y.

NASH, HERBERT, Jr., Electrical Engineer, Moors & Cabot, 111 Devonshire St.; res., 245 Newbury St., Boston, Mass.

WESTON, GEORGE, Member of Board of Supervising Engineers, Chicago Traction, 105 South La Salle St., Chicago, Ill.

Associates Elected February 14, 1913

Anderson, William Harrington, Inspector in Testing Bureau, Brooklyn Rapid Transit Co., Williamsburg Power Sta., Brooklyn, N. Y.

Annett, Fred Anzley, Instructor in Electrical Machinery, New York Electrical School, 39 West 17th St., New York, N. Y.

Bakker, Gerard Jacob Theodore, Adjunct-Director, Municipal Central Electric Works, The Hague, Holland.

Barnard, Robert B., Salesman, Westinghouse Electric & Mfg. Co., Butte, Montana.

Bassett, John B., Student Engineer, General Electric Co.; res., 1202 Union St., Schenectady, N. Y.

Beebe, Lester H., Engineer Salesman, General Electric Co.; res., 2834 Stephenson Ave., Los Angeles, Cal.

Beekman, Royce Allen, Electrical Engineer, Power & Min. Engg. Dept., General Electric Co.; res., 24 State St., Schenectady, N. Y.

Belsky, Charles James, Assistant Electrical Engineer, Railroad Commission of Wisconsin; res., 306 Murray St., Madison, Wis.

Berry, Wallace Noyes, Electrician, Albuquerque Gas, Elec. Light & Power Co., Albuquerque, N. M.

Boright, George Kenric, Assistant District Engineer, Canadian Westinghouse Co., Ltd., 52 Victoria Sq., Montreal, Que.

Bower, George W., Asst. Engineer, Railway Equipment Dept., General Electric Co.; res., 28 Swan St., Schenectady, N. Y.

Bowes, Laurence C., Student, Sibley College, Cornell University; res., 201 Dryden Rd., Ithaca, N. Y.

Bradford, P. L., Test Engineer, General Electric Co.; res., Y. M. C. A., Erie, Pa.

Branson, Edward H., Electrical Engineer, Testing Dept., General Electric Co., Schenectady, N. Y.

Brunn, Georg Theodor, Electrical and Mechanical Engineer, Westinghouse Electric & Mfg. Co., Pittsburgh; res., 501 Pitt St., Wilkinsburg, Pa.

Cadiry, M. A. S., Consulting General Engineer, Cadirian Works, Ahmednagar, India.

Carlson, Alfred, Special Inspector, Central Union Tel. Co.; res., 1133 Sunnyside Ave., Chicago, Ill.

Catlin, Welles G., Instructor in Electrical Engineering, Cornell University; res., 418 Utica St., Ithaca, N. Y.

Chinlund, Joseph F., Designing Electrical Engineer, Office of City Engineer, City Hall; res., 3756 Sheffield Ave., Chicago, Ill.

Clarkson, Ralph Preston, Professor of Engineering, Acadia University, Wolfville, N. S.

Cleveland, Charles E., Instructor in Electrical Dept., Portland School of Trades; res., 569 E. 59th St., Portland, Oregon.

Cogswell, Frederick R., Load Dispatcher, Pittsburgh Railways Co., 435 6th Ave.; res., 237 N. Dithridge St., Pittsburgh, Pa.

Coxon, George Howard, Operating Superintendent, Vera Cruz Electric Light, Power & Trac. Co., Vera Cruz, Mex.

Darrow, Raymond Cornwell, Assistant in Eng. Dept., American Tel. & Tel. Co., 15 Dey St., New York, N. Y.

de Romana, Albert Lopez, Testing Dept., General Electric Co.; res., 225 Seward Place, Schenectady, N. Y.

de Windt, J. P. H., Jr., General Manager, Shore Line Electric Railway Co., Saybrook Junction, Conn.

Doane, Robert E., Electrical Engineer, Standard Underground Cable Co.; Pittsburgh; res., 315 Barnes St., Wilkinsburg, Pa.

Dobson, William Percy, Research Scholar in Electrical Engineering, University of Toronto, Toronto, Ont.

Du Bois, T. Randall, Electrical Engineer, Starter Dept., United States Light & Heating Co., Niagara Falls, N. Y.

Dushman, Saul, *Ph. D.*, Research Laboratory, General Electric Co.; res., 1593 Union St., Schenectady, N. Y.

Erickson, Charles J., Electrical Engineer, Automatic Electric Co.; res., 3748 Maple Square Ave., Chicago, Ill.

Fraser Alexander S., Superintendent, Smiths Falls Electric Power Co.; res., Slys Rapids, Smiths Falls, Ont.

Freeman, Horace, London Manager, Electrical Engineer Institute of Correspondence Instruction, 13 Southampton St., High Holborn, London, Eng.

Furst, Walter Albert, Electrical Engineering Dept., Baltimore & Ohio Railroad; res., 2130 W. Baltimore St., Baltimore, Md.

Goodwin, Philip H., Electrician, Pond Creek Coal Co., Mine 3, Williamson, W. Va.

Gordon, Victor D., Electrical Engineer, Shearer Electric Construction Co., Mexico City, Mex.

Gundlach, William E., Milwaukee Electric Ry. & Light Co., res., 1004 Bartlett Ave., Milwaukee, Wis.

Hackenberg, Harvey J. A., Electrical Engineer, Adams-Bagnall Electric Co., Cleveland; res., 1568 Grace Ave., Lakewood, Ohio.

Hart, John Porter, Draftsman, Portland, Eugene & Eastern Ry. Co.; res., 533 E. 17th St., North, Portland, Ore.

Hartzell, Ross Calvin, Chief Electrician, Columbus, Municipal Electric Light Plant; res., 1386 Neil Ave., Columbus, Ohio.

Hemmenway, Laurence T., Sales Dept., General Vehicle Co., Inc., Long Island City; res., 143 Kent St., Brooklyn, N. Y.

Henrichsen, Christian, Electrical Engineer, General Electric Co.; res., 292 North St., Pittsfield, Mass.

Hoffman, Henry A., General Electric Co.; res., 231 Seward Place, Schenectady, N. Y.

Hoyt, Walter S., Interborough Rapid Transit Co., 148th St. & 7th Ave., New York; res. 57 Halsey St., Brooklyn, N. Y.

Humphrey, George S., Distribution Engineer, Utah Power & Light Co., Salt Lake City, Utah.

Jeffery, Richard T., Electrical Engineer, Smith, Kerry & Chace; res., 42 North St., Toronto, Ontario.

Jesperson, C. M., Salesman, Westinghouse, E. & M. Co.; res., 12 Hubbard Court, Charleston, W. Va.

Kaplan, Eugene V., Assistant Master Mechanic, West Penn Railways Co.; res., 207½ E. Washington Ave., Connellsville, Pa.

Keeler, Hugh Edward, Student, University of Michigan; res., 503 William St., E. Ann Arbor, Mich.

Kent, Stanley B., Telephone Engineer, Western Electric Co., Chicago; res., 4822 W. 22nd Place, Cicero, Ill.

Kobrock, John P., Division Plant Engineer, Missouri & Kansas Tel. Co., 306 N. 10th St., St. Joseph, Mo.

Lamb, Carter Herbert, Electrical Engineer, The Arnold Co.; res., 656 North 53rd Ave., Chicago, Ill.

Lamberton, Horace C., Signal Foreman, Louisville & Nashville R.R. Co., Louisville, Ky.

Long, George J., Consulting & Contracting Electrical Engineer, Webster City, Iowa.

Long, Hollis Branscomb, Electrical and Hydraulic Engineer, Tennessee Inspection Bureau, 1034 Stahlman Bldg., Nashville, Tenn.

Lufkin, Fred Richards, with Walter B. Snow, Room 426, 170 Summer St., Boston; res., 43 Summer St., Watertown, Mass.

Martin, Edwin R., Asst. Instructor, Dynamo Laboratory, Sheffield Scientific School, New Haven, Conn.

Mayo, Clarence Arthur, Superintendent, Peoples Gas and Electric Co.; res., 101 West Sixth St., Oswego, N. Y.

Mayott, Clarence Wilbur, Assistant Superintendent of Power, Hartford Electric Light Co.; res., 54 Main St., Hartford, Conn.

McDowell, Thomas Sydney, Supply Dept., Mexican General Electric Co., Mexico City, D. F.

Morgan, John Davis, Williamsburg Power Station, Brooklyn Heights Railroad Co.; res., 179 Marcy Ave., Brooklyn, N. Y.

Morris, Hurd T., Engineering Dept., Railway Div., Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Moyer, Leonard M., Switchboard Engineer, General Electric Co.; res., 211 Seward Place, Schenectady, N.Y.

Neumann, Stanislaus G., Electrical Engineering Student, Bliss Electrical School, Washington, D. C.

Palmer, John, Erecting Engineer, Canadian Westinghouse Co., Hamilton; res., Kenogami, Ont.

Parish, Leonard George, Assistant Electrical Engineer, American Steel & Wire Co.; res., 12 Howland Terrace, Worcester, Mass.

Prince, Ernest, Student Apprentice, Allis Chalmers Co.; res., 1841 Athers St., Boulder, Colo.

Ramey, Blaine B., Electrical Engineer, Crocker-Wheeler Co., Ampere, res., 29 N. 17th St., East Orange, N. J.

Ramay, Joseph W., Instructor in Electrical Engineering, University Station; res., 207 East 26th St., Austin, Texas.

Riggs, Leland W., Designing Engineer, A. C. Engg. Dept., General Electric Co.; res., 785 State St., Schenectady, N. Y.

Roberts, Douglas A., Asst. Superintendent Substations, Illinois Traction System, Springfield, Ill.

Rogers, Frederick Jr., Resident Agent, General Electric Co., Massachusetts Mutual Bldg., Springfield, Mass.

Schirmer, August H., Telephone Engineer, American Tel. & Tel. Co., New York, N. Y.; res., 59 Quitman St., Newark, N. J.

Scrivener, Robert W., Sales Engineer, Alfred Collyer & Co., Montreal; res., 165 Marlboro Ave., Toronto, Ont.

Shepard, James A., Electrical Engineer, Tucson Gas, Electric Light & Power Co., Tucson, Arizona.

Short, Frank, Student, Cornell University, Ithaca, N. Y.

Silsbee, Francis B., Asst. Physicist, Bureau of Standards; res., 1924 H St., Washington, D. C.

Skipwith, Lee, Purchasing Agent, Federal Light & Traction Co.. New York, N. Y.; res., 422 Kimball Ave., Westfield, N. J.

Smith, Arthur Vinton, Electrical Repair and Construction Work, 90 Park St., Ashtabula, Ohio.

Smith, Harold Elbert, Philadelphia & Reading Coal and Iron Co., Pottsville, Pa.

Smith, Paul Raymond, Student Instructor, General Electric Co.; res., Holmes Road, Pittsfield, Mass

Smith, Sidney Edward H., District Manager, Canadian Sunbeam Lamp Co., Ltd.; res., 846 Howe St., Vancouver, B. C.

Snider, Robert A., Asst. Mechanical Engineer, Berwind White Coal Mining Co.; res., Wilmore Club, Windber, Pa.

Speight, Herbert, Electrician, Granby Mines, Anyox, B. C.

Standing, Alfred John, Asst. Supt., Elect. Dept., Bethlehem Steel Co., So. Bethlehem; res., 445 Cherokee St., So. Bethlehem, Pa.

Stevenot, Josephus Emile, Electrical Engineer, E. C. McCullough Co., Manila, P. I.

Stevenson, T. Kennedy, Chief Engineer, Duplex Metals Co., Room 740, 30 Church St., New York, N. Y.

Sticht, Herman H., Sales Engineer, J. G. Biddle, Room 1020, 90 West St., New York, N. Y.

Stickney, H. Russell, Edison Electric Illuminating Co., 360 Pearl St., Brooklyn, N. Y.

Sunnergren, Arvid Peter, Westinghouse Electric & Mfg. Co.,Pittsburgh, res., 834 Ramsey Ave., Wilkinsburg, Pa

Taylor, Almon Vincent, Professor of Electrical Engineering, North Dakota State School of Science, Wahpeton, N. D.

Thomen, Martin K., Draftsman, Empire District Electric Co.; res., 314 W. 9th St., Joplin, Mo.

Todd, William J. S., Engineer, Department of Public Works; res., 71 May St., Edmonton, Alberta.

Treweeke, Frank Lesley, Line Foreman, Mexican Light & Power Co., Mexico City, Mex.

Trout, Benton Reeves, Switchboard Operator, Great Falls Power Co., Great Falls, Mont.

Twaddle, Harry L., 2nd Lieut., Fort Wright, Spokane, Wash.

Vinet, Eugene, Electrical Engineer, Shawinigan Water & Power Co., Montreal; res., 343 de L'Epee Ave., Outremont, Quebec.

Wade, Guy Walter, Transformer Engineer, General Electric Co.; res., 40 Bartlett Ave., Pittsfield, Mass.

Walker, Duncan I., Chief Operating Engineer, Vancouver Island Power Co., Jordan River Station, Victoria, B. C.

Wheelock, Jesse Franklin, Operator, Pacific Gas and Electric Co., Colgate Power House; res., Dobins, Cal.

Whyte, Andrew C., Mechanical Engineer, General Electric Co., New York, N. Y.; res., 161 Park St., Ridgefield Park, N. J.

Total 101.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute as Associates. These applications will be considered by the Board of Directors at a future meeting. Any member of the Institute objecting to the election of any of these candidates should so inform the Secretary before March 25, 1913.

Adey, C. C., Watervliet, N. Y.
Ball, A. P., Grand Rapids, Mich.
Beery, E. J., Seattle, Wash.
Binns, C. A., San Mateo, Cal.
Biscayart, L., Montreal, Can.
Bishop, F. L. Pittsburgh, Pa.
Blade, E. H., San Francisco, Cal.
Blanchard, C. R., Pittsfield, Mass.
Brooks, J. W., Jr., Toronto, Ont.
Brooks, W. L., Schenectady, N. Y.
Burgner, H. T., Venice, Ill.
Caldwell, O. H., New York, N. Y.
Cole, C. R., Vancouver, B. C.
Corry, J., Newark, N. J.
Cramer, H. P., Portland, Ore.
Dotterweich, A. J., Wilkinsburg, Pa.
Ebert, S. G., New York, N. Y.
Edwards, J. L., Wilkinsburg, Pa.
Fairchild, A. C., Northumberland, Pa.
Funkhouser, L. A., Gary, Ind.
Geither, E. C., New York, N. Y.
Greisser, V. H., Spokane, Wash.
Griffiths, W., Ft. Wayne, Ind.
Harding, A. L., Boston, Mass.
Hutchinson, M., Victoria, B. C.
Ives, E. C., Madras, S. India.
Jones, L. D., Schenectady, N. Y.
Kirlin, I. M., Watertown, S. D.
Knapp, L. H., Schenectady, N. Y.
Koiner, J. S., Syracuse, N. Y.
Krom, A. H., Chicago, Ill.
Krone, W. E., Pittsfield, Mass.
Leigh, W. E., New York, N. Y.
Martin, S. H., Chicago, Ill.
McCullough, H. F.,Niagara Falls, N. Y.
Middlemiss, G. H., Sacramento, Cal.
Miller, T. L., Toledo, O.
Moreton, J. W., New York, N. Y.
O'Donovan, J. S., Sharpsburg, Pa.
Orange, J. A., Schenectady, N. Y.
Ostrom, W. A., Saskatoon, Sask.
Outcalt,W. M., Avondale, Cincinnati, O.
Parker, W. F., Chicago, Ill.
Pierce, A. W., West Chester, Pa.
Plank, H. E., Portland, Ore.
Pratt, H. H., Winnipeg, Man.
Purdy, H. T., San Jose, C. R.,
Rose, T. D., Baltimore, Md.
Ross, A., Oglesby, Ill.
Sanders, J., Danbury, Conn.
Scheel, C. F., Cicero, Ill.

Seidler, E., Vancouver, B. C.
Seirad, A. E., Wilkinsburg, Pa.
Sohlberg, G., Schenectady, N. Y.
Speer, G. F., Boston, Mass.
Stafford, R. W., New York, N. Y.
Steeves, J. T., Montreal, Can.
Stephens, J. H., Washington, D. C.
Stokes, H. E., Pittsburgh, Pa.
Taylor, F. C., Rochester, N. Y.
Timothy, F B., New York, N. Y.
Trimble, A. V., Toronto, Ont.
Twisden, H. S., Lynn, Mass.
Ulrich, B. H., Pittsburgh, Pa.
Walker, E. M., Dubuque, Ia.
Whitney, R. D., Syracuse, N. Y.
Wise, E. M., Jr., Schenectady, N. Y.
Woolverton, R. B., San Francisco, Cal.
Worth, C. C., New York, N. Y.
Total 69

Students Enrolled February 14, 1913

5615 Steiskal, O., Lewis Institute.
5616 Gonnsen, H. P., Lewis Institute.
5617 Shave, S. R., Univ. of Wash.
5618 Turner, J. W., Armour Institute.
5619 Berlin, W. G., Penna. State Coll.
5620 Pinkham, R. A., Univ. of Maine.
5621 Dupere, E. J., Lewis Institute.
5622 Wright, A. J., Univ. of Toronto.
5623 Edwards, J. H., State Univ. Iowa.
5624 Forde, W. H., Yale University.
5625 Post, F. B., Univ. of Washington.
5626 Bruggeman, J. G., Univ. of Cin.
5627 Achard, F. H., Mass. Inst. of Tech.
5628 Davis, R. H., Wash. State Coll.
5629 Walker, G. A., Univ. of Nebraska.
5630 Kinney, H. S., Univ. of Nebraska.
5631 Howlett, T. F., Univ. of Toronto.
5632 Truman, J. K., Mont. State Coll.
5633 Edwards, G. D., Harvard Univ.
5634 Felt, W. L., A. & M. Coll. of Tex.
5635 Randall, Jr., H.E., Mass. Inst. Tech.
5636 Reese, C. E., Rose Poly. Inst.
5637 Thomson, D. J., Univ. of Toronto.
5638 Hill, T. A., Univ. of Toronto.
5639 Milburn, W. R., Ohio State Univ.
5640 Plumer, W. A., Ohio State Univ.
5641 Duncan, W. G., Univ. of Toronto.
5642 Glein, E. J., Univ. of Colorado.
5643 Cavers, R. L. G., Univ. of Colo.
5644 Stone, V. D., Kans. S. Agr. Coll.
5645 Ipsen, C. L., Kans. S. Agr. Coll.
5646 Parker, H. O., Kans. S. Agr. Coll.
5647 Graham, F. H., Kans. S. Agr. Coll.
5648 Jenson, L. L., Kans. S. Agr. Coll.
5649 Lewis, F. C., Kans. S. Agr. Coll.
5650 Ellis, F. C., Kans. S. Agr. Coll.
5651 Perry, S., Univ. of Cincinnati.
5652 Heriot, H. A., Clemson Agr. Coll.
5653 Pearson, J. F., Clemson Agr. Coll.
5654 Rivers, Jr., H.F., Clemson Agr. Coll.
5655 Evans, A. B., Clemson Agr. Coll.
5656 McIntyre, D., Clemson Agr. Coll.
5657 Hall, J. D., Clemson Agr. Coll.
5658 Brown, A. J., Clemson Agr. Coll.
5659 Hilker, P., Univ. of Texas.
5660 Crawford, M. C., Univ. of Texas.
5661 Strauss, C. M., Univ. of Texas.
5662 Palmer, C. G., Univ. of Texas.
5663 Morris, F., University of Texas.
5664 Fort, W. F., University of Texas.
5665 Fitzhugh, T. C., Univ. of Texas.
5666 Jones, H. L., Univ. of Texas.
5667 Quebedeaux, W.C., Univ. of Texas.
5668 Martin, C. L., Univ. of Texas.
5669 Files, S. J., Univ. of Texas.
5670 Porch, Jr., E.L., Univ. of Texas.
5671 Keck, W. E., University of Texas.
5672 Cooper, A. E., Univ. of Texas.
5673 Hutchinson, O.C.K., Armour Inst.
5674 Schoembs, A.F., Armour Institute.
5675 Cohn, J. W., Armour Institute.
5676 Schnure, F. O., Bucknell Univ.
5677 Whittaker, L. A., R. I. S. Coll.
5678 Gautier, F. L., Univ. of Cal.
5679 DeCamp, S. M., Purdue Univ.
5680 Brenneman, J. L., Univ. of Wis.
5681 Harris, C. B., Univ. of Nebraska.
5682 Griffin, R. C., Univ. of Cal.
5683 Penquite, P., Ohio Northern Univ.
5684 Hall, H.G., University of Toronto.
5685 Anderson, J. A., Lewis Institute.
5686 Phares, L. S., Univ. of Nebraska.
5687 Stocking, S. I., Rose Poly. Inst.
5688 Nilson, J. H., Ohio Northern Univ.
5689 Watson, E. F., Cornell University.
5690 Christensen, M. F., Pratt Inst.
5691 Jamison, R. B., Univ. of Penna.
5692 Rile, A. D., Univ. of Penna.
5693 Sharp, M. C., Univ. of Toronto.
5694 Park, A. D., Clemson Agr. Coll.
Total 80

Past Section Meetings

BOSTON

On January 22, in Tremont Temple, there was held a joint meeting of the Boston Sections of the A. I. E. E., the American Society of Civil Engineers and the American Society of Mechanical Engineers. Mr. Rollins, president of the Boston Society of Civil Engineers, presided, and there was a total attendance of about 225.

The speaker of the evening was Mr. William H. Lewis, president of the Lewis-Wiley Hydraulic Company of Seattle Wash., and Portland, Ore., and his subject was " Hydraulics in City Building."

This company performed the work of the famous regrades in Seattle, whereby Denney Hill and Jackson Street Hill grades of 15 to 20 per cent were reduced to grades of three to five per cent, the material being used to fill the tide lands on the waterfront which now constitute the entire terminals of the Great Northern, Northern Pacific and Union Pacific Railroad companies. The work of the company in Portland has been that of reducing a rough and inaccessable hill by hydraulic terracing, and so converting it into one of the choicest residential portions of the city. This work was done under the plans of Olmsted Brothers of Brookline, Mass.

Mr. Lewis illustrated his talk by lantern slides.

CHICAGO

At the meeting of the Chicago Section on January 27, Mr. B. G. Lamme, chief engineer of the Westinghouse Electric and Manufacturing Company, made an address on " The Desirability of Revising the Rating and Methods of Testing Electrical Apparatus." There were approximately two hundred members present at the meeting and many of them joined in the discussion following Mr. Lamme's address.

FORT WAYNE

A meeting of the Fort Wayne Section was held on January 16 at the Commercial Club, with Chairman T. W. Behan presiding. Dr. M. W. Franklin, of the General Electric Company, gave a talk on the subject of " Ozone, Its Manufacture and Commercial Application." There was a total attendance of 22 at the meeting.

INDIANAPOLIS—LAFAYETTE

The regular December meeting of the Indianapolis-Lafayette Section was held on the evening of December 6, 1912, in the roof garden of the Central Union Telephone Company Building at Indianapolis. Sixty-three members and visitors, including a large number from Purdue University at Lafayette, were present to hear Mr. Arthur J. Sweet, commercial engineer of the Holophane Company, speak on the subject of " Reflecting Media."

Mr. Sweet first called attention to the widespread but erroneous idea that all reflecting media obey the law that " the angle of reflection equals the angle of incidence." Reflecting media do not all reflect light in obedience to the same law. Instead, there are three separate and independent laws in accordance with which reflection of light is accomplished, and each type of reflecting medium is classified with respect to the particular law under which it operates.

Under the law of *specular reflection*, a beam of light received on the reflecting surface is reflected in a single direction, this direction, or angle of reflection, being equal to the angle of incidence. Clear prismatic reflectors, silvered glass reflectors, and polished metal reflectors obey the law of specular reflection. These types of reflecting media permit the attainment of the maximum degree of light control.

Under the law of *diffuse reflection*, a beam of light striking the reflecting surface is reflected in all directions, the intensities in each direction being represented by the chords of a circle drawn tangent to the reflecting surface at the point of reflection. Opal or white glass reflectors of all types whatsoever, porcelain-enameled metal reflectors, and ordinary walls and ceilings obey the law of diffuse reflection. These reflecting media give a very limited degree of light control.

Under the law of *spread reflection* a beam of light striking the reflecting surface is reflected for the most part in a single direction, but with a certain spreading of the rays. Satin-finish prismatic reflectors and aluminized metal reflectors obey the law of spread reflection. These reflecting media give an appreciably greater degree of light control than diffuse media but a materially lesser degree of light control than specular media.

After presenting and thoroughly explaining these three general laws, Mr. Sweet demonstrated their application to various well-known types of reflecting media by an extensive series of photometric curves and tables.

The presentation of the paper was followed by a full discussion which demonstrated the interest of the audience in the subject.

Chairman O. S. More presided at this meeting.

The next regular meeting of the Indianapolis-Lafayette Section was held in the Electrical Engineering Building at Purdue University, Lafayette, January 14. Professor C. F. Harding was in the chair. About 150 members, students and visitors were present, to hear Mr. J. L. Buchanan, district transformer engineer of the General Electric Company, on "Details of Transformer Manufacture."

Mr. Buchanan exhibited a large number of slides showing the process of manufacture from the punching of sheet steel to the testing of the finished product. He also called attention to the advance in design made possible by the use of silicon steel, and to the fact that above 100,000 volts the ratio of primary to secondary voltage did not correspond to the ratio of the number of turns.

Different types of lightning arresters were also described, particular attention being given to the compression chamber multigap type for distributing circuits.

ITHACA

On the evening of January 11 the sixth annual banquet of the Ithaca Section was held in Sibley Hall of Cornell University, with about 120 attending. Professor E. L. Nichols was toastmaster.

The first speaker was Professor G.S. Macomber, who gave a " History of the Morse Telegraph Instrument." Mr. John L. Harper, chief engineer of the Niagara Falls Hydraulic Company, spoke on " Power Developments at Niagara Falls." Professors Vladimir Karapetoff, Dexter S. Kimball and Henry H. Norris were called upon to speak on " the why, what, where, which how, who, when, etc." of electricity. President Ralph D. Mershon then talked on the subject of " Personal Experiences in Pioneer Electrical Power Transmission."

The Cornell banjo club quartette furnished music between the speeches. An interesting feature of the evening was the exhibition of the old Morse telegraph recorder which was used in opening the famous Baltimore-Washington line in 1844 to record the message " What hath God wrought." The old instrument was not only on exhibition, but in actual service, and on it a message was received during the banquet from Past President Gano Dunn.

LOS ANGELES

The Los Angeles Section held its regular monthly meeting at the Hotel Hollenbeck, on January 28.

Chairman George A. Damon presided. There were present 74 members and visitors.

Mr. Damon introduced Mr. Ralph D. Mershon, president of the Institute, who was the guest at this meeting. Mr. Mershon made an address, reviewing the recent adoption of the new grade of membership in the Institute, also discussing the possibility of a

Pacific Coast Convention of the Institute for Los Angeles in 1914, and the patent situation in the United States.

The paper of the evening was "The Planning of Industrial Cities with Special Reference to Public Utilities," by Mr. Ralph Bennett. Mr. Bennett's paper covered the general layout of streets and railroad rights of way, the location of railroad tracks for both freight and passenger service, the location of the business and residence sections with reference to the industrial plants, the location of utilities, other than railroads, throughout the property, and the use of alleys for this purpose, and the limitations imposed upon the best technical layouts by the necessity of land utilization. The paper was illustrated by stereopticon views showing the construction work in progress in the new industrial city of Torrence.

The following took part in the discussion: Messrs. Ralph Bennett, H. H. Sinclair, G. A. Damon, I. F. Dix, J. E. Macdonald, R. E. Cunningham and Budd Frankenfield.

Minnesota

A meeting of the Minnesota Section was held on January 13 at the Cafe McCormick, Minneapolis. There was a total attendance of 35, and Chairman A. L. Abbott presided.

Mr. E. J. Heinen presented a paper on "Economy Gained by the Use of CO_2 Recorders," showing a number of original curves to demonstrate graphically the relation between CO_2 and the coal pile. Following Mr. Heinen's paper, Mr. W. C. Beckjord and Mr. L. A. Stenger gave short talks on "Boiler and Turbine Testing."

Pittsburgh

The meeting of the Pittsburgh Section on January 14 in the rooms of the Engineers Society of Western Pennsylvania was attended by 50 members and visitors. Chairman E. L. Farrar presided.

The paper of the evening, "Maintenance of Operation During Construction Work," was presented by Mr. G. N. Lemmon, consulting engineer. Mr. Lemmon said that continuity of service is the prime requisite for the central station and railway operator. Numerous slides were shown of construction work at Reading, Pa., in changing a line from 11,000 to 22,000 volts, operation being maintained continuously.

A discussion followed the reading of the paper, which was participated in by Messrs L. O. Veser of the Mahoning and Shenango Railway Company, G. C. Hecker of the Pittsburgh Railways Company, J. S. Jenks of the West Penn Traction and Water Power Company, K. C. Wandall and P. M. Lincoln of the Westinghouse Electric and Manufacturing Company, Henry Harris of the Wilmerding Electric Company, and William Oschman of the Oliver Iron and Steel Company.

Mr. Veser had been engaged on the Reading job described by Mr. Lemmon, and said it had been possible to work only on dry days on account of the leakage from the lines on wet days. It was an unusually dry season and it was possible to work about 100 days out of the four-month period involved. Gangs of three linemen and one groundman were used; generally two gangs. Working at maximum efficiency, it took about 20 minutes to change a pole; and an average day's work (9 hours) was about 10 or 11 poles. The maximum was 29 poles. Some days only five or six were changed, due to corner or double-arm poles. The work on the corners was very hazardous, and could not be done while the line was "hot;" consequently, it had to be done on Sundays when interruption did not mean so much. The tying in was always done on a dead line. No serious accidents occurred during the work. The dead line was always grounded, or, rather, short-circuited, and no one touched it until he was sure it was "dead." The cost of the entire work amounted to $475 per mile, including labor, crossarms, insulators, etc. The cost of labor per pole (single-arm) amounted to about $1.50. It was found that the crossarms were suffering from dry rot. The poles were of chestnut and had been in service about 10 or 12 years, and no sign of rot or decay, even in the gains, was found.

Mr. Hecker described the installation of some 11,000-volt units replacing some 2200-volt sets at the Brunot's Island power house of the Pittsburgh Railways Company.

Mr. Lincoln said he could appreciate the troubles of the operating man, as he had been one for seven years. The first law and gospel of the operating man was to "*keep the juice on the line.*" Loyalty was very common among operating men; they were generally ready to jump in and help. He never gave an order to work on "hot" lines, but sometimes found it convenient to accept volunteers for this work.

Mr. Jenks told of a number of instances of reconstruction work. He said the financiers would usually approve any expenditure for "continuity of service." He had succeeded in attaining a *time efficiency* of 99.399 per cent on his lines, but the last three nines were hard to get. During the last season they had replaced 170 poles and 1800 crossarms with no interruptions. He had moved a 22-panel switchboard bodily from one part of the plant to another without interrupting service. Leads were spliced on of the proper length, and then the board lifted by the crane. Such work, however, is very costly and is difficult to estimate accurately.

PITTSFIELD

Professor E. E. F. Creighton of the consulting engineering department of the General Electric Company addressed the Pittsfield Section on January 29 at the Y. M. C. A. Building on the subject of "Standing Waves."

After outlining the theory of impulses, oscillations, traveling and standing waves, the speaker demonstrated the phenomena by means of a rope made of a spiral spring and by an ingenious mechanical device, which showed two traveling waves moving in opposite directions, and their combination into a stationary wave. The waves were also demonstrated electrically by means of an artificial open-ended line and a resonance circuit.

The attendance was 102, and 19 attended the informal dinner at the Hotel Wendell preceding the address. Chairman W. C. Smith presided.

PORTLAND, ORE.

The regular January meeting of the Portland Section was held in the club rooms of the Oregon Technical Club, on January 21.

After transacting considerable routine business, the Section heard a paper on the subject of "Transformer Connections," which was presented by Professor W. A. Hillebrand of the electrical engineering department of the Oregon Agricultural College. A discussion followed the presentation of the paper.

The attendance was 35, including 4 visitors. Chairman H. R. Wakeman presided.

ST. LOUIS

The Engineers' Club of St. Louis, with which the St. Louis Section is affiliated, is considering the advisability of erecting a building suitable for the use of the associated engineering societies of the city.

The committee which has this matter under consideration requested the St. Louis Section of the Institute to indicate what co-operation it would be willing to give in this matter, and a special business meeting was held on January 22 to discuss this question. The meeting was attended by 15 members, and, in the absence of the chairman, Mr. J. A. Kraeuchi presided.

The need for larger quarters than the present leased rooms has been felt for some time, and the present discussion of the matter is the outcome of this growing need. The Section did not take any definite action, except to appoint a committee to consider the project, and confer with the committee of the Engineers' Club.

On January 25 the first annual dance of the St. Louis Section was held in the ballroom of the Missouri Athletic Club. While not as well attended as might have been desired, it was a decided success and the feeling was general among the members that it should be the first of many such enjoyable occasions.

SAN FRANCISCO

On January 24, the San Francisco Section tendered a banquet at the Old Poodle Dog Restaurant in honor of President R. D. Mershon, who has been on a few weeks' trip to the coast. The meeting was attended by 136 members and guests. Chairman H. W. Crozier presided. A complete program of entertainment was provided, among some of the features being popular songs and skits by students from the University of California and Leland Stanford, Jr., University Branches.

The enthusiasm of the banquet was represented graphically in the form of an " enthusiastic curve," the " peak " coming on when Mr. Mershon made a general talk on Institute matters.

SCHENECTADY

The 119th meeting of the Schenectady Section was held on January 21 in the Congregational Church Hall, with a total attendance of 175. Mr. J. R. Craighead presided.

This was a discussion meeting, the subject being " Modern Electric Railway Practise." The discussion was led by Messrs. B. L. Delack, A. J. Woodward, J. A. Dewhurst, J. J. Linebaugh, S. T. Dodd and S. B. Fortenbaugh. The meeting was then thrown open for general discussion and answering of questions.

The informal nature of these discussion meetings has made them very popular, especially with the younger members of the Section.

SEATTLE

The regular monthly meeting of the Seattle Section was held on January 18 in the assembly hall of the Chamber of Commerce. There was an attendance of 21, and Mr. A. A. Miller presided.

After the routine business had been despatched, a paper on " Electric Welding " was presented by Mr. W. Montelius Price. Several samples of electrically welded articles were exhibited. Messrs. Miller, Magnusson, Hoskins, Terrell, Lindsay, Howes, Lord, Loew and Dunbar participated in the discussion.

TORONTO

The regular monthly meeting of the Toronto Section was held at the Engineers' Club, Toronto, on the evening of January 17, 1913.

The meeting was called to order by the chairman, Mr. F. A. Gaby, who introduced Mr. W. W. Sweany and Mr. J. G. Jackson of the Toronto Hydro-Electric System. Mr. Sweany presented a paper on " The Practicability of the Toronto Street Lighting System," and Mr. Jackson read a paper entitled " Notes on the Construction of the Toronto Hydro-Electric System." Both papers were illustrated in an interesting manner by stereopticon views.

There was a total attendance of 175 at the meeting.

VANCOUVER, B. C.

The regular monthly meeting of the Vancouver Section was held in the University Club, Vancouver, B. C., on December 6, 1912, 32 members and six visitors being present. Chairman F. D. Nims presided.

Mr. Montgomery requested the secretary to read a letter issued by the National Electric Light Association concerning House Bill No. 25782—" A bill to establish in the Department of Agriculture a bureau of farm power," and also to read the bill. The bill having been read and discussed, it was moved and carried that the secretary write to the Board of Directors of the A. I. E. E. advising that the Vancouver Section after discussing this bill had unanimously signified its approval of it, and the intention of supporting it as far as possible.

Mr. C. H. Fletcher, the city electrician, then read the new City By-Laws covering electrical wiring and installation, and a discussion followed, in which a great deal of information was obtained from Mr. Fletcher.

The regular meeting of the Section was held January 10 at the University Club, and was called to order by Chairman F. D. Nims.

A report was made by Mr. L. G. Robinson in regard to the progress of the work of the co-operation committee.

A very comprehensive digest of the two papers on high-tension insulators, *Comparative Tests on High-Tension Suspension Insulators*, by P. W. Sothman, and *High-Frequency Tests on Line Insulators*, by L. E. Imlay and Percy H. Thomas, was given by Mr. R. F. Hayward, a member of the High-Tension Transmission Committee, and was followed by an interesting discussion. Mr. W. H. R. Fraser gave some facts concerning operating results on the Ontario Hydroelectric System, and Mr. L. G. Robinson presented some figures concerning high-tension insulators on the Shawinigan Water and Power Company's system.

The total attendance at the meeting was 32.

WASHINGTON, D. C.

A meeting of the Washington, D. C., Section was held on January 14, in the Telephone Building. Commander W. H. G. Bullard, U. S. N., presented a paper on "Radio-Communication and Its Use in the United States Navy."

Chairman J. H. Finney presided at the meeting, at which the attendance was 80.

Past Branch Meetings

UNIVERSITY OF ARKANSAS

A meeting of the University of Arkansas Branch was held on December 11, 1912. Professor Carnahan of the mechanical engineering department discussed "The Testing of Flue Gases," an Institute paper was read by Mr. P. Valentine, and a paper on "The Installation of the New Cincinnati Lighting System" was presented by Mr. S. M. Snodgrass.

At the meeting of the Branch on January 22, Mr. T. M. Northum read a paper on "Industrial Lighting." Mr. Homer Dunn then spoke on "Current Events," after which the members present engaged in a general discussion of some lighting problems.

ARMOUR INSTITUTE OF TECHNOLOGY

The meeting of the Armour Institute of Technology Branch on December 5, 1912, was addressed by Mr. P. A. Copenhaver, on the subject "The Applications of Electricity to Gasoline Automobiles." Mr. Copenhaver called attention to the use of electricity for starting gasoline engines, for lighting, and for ignition, but devoted most of his paper to the use of electrical energy for starting purposes. The various types of dynamos and motors used for self-starters were discussed. In some systems a separate generator and motor are used; in others only one machine is employed, which acts as a motor to start the engine, taking current from a storage battery, and later acts as a generator to charge the storage battery and supply the electric lamps, current for ignition also being taken from the battery.

A special meeting and banquet of the Branch was held on December 18, 1912, at the Boston Oyster House, with an attendance of 30. After the banquet the meeting was addressed by Mr. G. E. Marsh, on "The Direct-Current System of Energy Transmission." Mr. Marsh said that, while this system has received

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little attention in this country, there are several waterpower plants in Europe which successfully transmit energy by direct current.

The essential features of the system are the connecting of several generators in series which deliver a constant current at a varying voltage to suit the load, and the operation at the receiving end of the line of several series motors connected in series, the motors being connected to electric generators of either the direct- or alternating-current type. The generators at the generating station may be operated at varying speeds, but the motors at the receiving stations are operated at constant speed by mechanically shifting the brushes or electrically controlling the field, or by both methods combined. A decided advantage of this system is the economy obtained in the transmission line and the simplicity of the switching devices. A serious disadvantage is that, up to the present, it has not been found practical to build a series generator of large size and operating at high voltage.

BUCKNELL UNIVERSITY

A meeting of the Bucknell University Branch was held on January 22, when Mr. R. L. Rooke spoke on the subject of " The Thury System of Continuous-Current Transmission of Power." The speaker discussed the history and details of operation of the system, and then compared it, as to cost and efficiency, with the high-tension alternating-current system of transmission.

UNIVERSITY OF CALIFORNIA

A meeting of the University of California Branch was held on January 28, when Mr. J. H. Moseley, Mackay Fellow in Electrical Engineering, presented a paper on " Load Factors." The speaker showed the load factors that exist at present on the systems of various power and lighting companies, street railways, steam railroads, central stations and isolated plants. It was shown what classes of business could be sought to smooth out the curves, and what effect changes would have on the earnings and investments of the plants; also, how the general load factor could be improved if these various companies could arrange to exchange power among themselves at certain times of the day, thus reducing the amount of equipment necessary to sustain their maximum peaks. The paper was followed by considerable discussion.

The members of the University of California Branch attended the dinner given by the San Francisco Section on January 24, on the occasion of President Mershon's visit.

CLEMSON AGRICULTURAL COLLEGE

The first regular meeting of the Clemson Agricultural College Branch was held on January 13, with a total attendance of about sixty. President Riggs read a paper on the history of the A. I. E. E. Professor W. C. Wagner presented an illustrated synopsis of Mr. F. C. Green's paper, ***Some Features of the Outdoor Electrical Installation***, published in the November, 1912, PROCEEDINGS, citing some instances of Western high-tension practise. Mr. J. H. Kangeter gave a paper on " The Southern Power Company's Developments," and synopses of current periodicals were given by Messrs. E. T. Provost, M. S. Lawton, D. M. Sloan and H. S. McGee.

COLORADO STATE COLLEGE

At the meeting of the Colorado State College Branch on December 7, 1912, Professor Rankin made an address on " The Fallacy of Installing Low-Voltage Lighting and Power Plants on the Farm."

A meeting of the Branch was held on January 27, when a paper on " The Mercury Arc Rectifier" was presented by Mr. R. O. Sewell. Mr. M. D. Work followed with a paper on " The Vibrating Rectifier," giving the efficiencies and comparative merits of the two types of apparatus.

UNIVERSITY OF COLORADO

At a meeting of all the engineering students of the University of Colorado in the afternoon of December 11, 1912, Mr. C. S. Pearse, past president of the National Association of Stationary Engineers, and chief engineer for Bennett and Meyers, of Denver, made an address on " The N. A. S. E. and Its Relation to Technically Trained Men." There was an attendance of 210 at the meeting.

At the regular meeting of the University of Colorado Branch on January 15, Mr. A. W. Ainsworth of the Ainsworth Standardizing Laboratory of the University of Colorado delivered an illustrated lecture on " Steam Turbines." With the aid of over 70 slides the speaker described the different types of both horizontal and vertical steam turbines, of various capacities, and also, using cross-sectional views, explained their mechanical details.

At the meeting of the Branch on February 5, Mr. W. F. Cozad of the Mountain States Telephone and Telegraph Company spoke on " Telephones and Telephone Switchboards." Mr. Cozad discussed the telephone development of the different countries of the world, comparing each case with the United States, the pioneer in the telephone industry. The speaker said that the telephone industry should not be under government control, as this had brought unsatisfactory results in various cases in Europe and Asia. Mr. Cozad then took up the operation and capacities of switchboards, and the manufacture of telephone equipment.

IOWA STATE COLLEGE

A meeting of the Iowa State College Branch was held on November 20, 1912, when Professor G. A. Gabriel lectured on " The Electrochemical Recovery of Tin from Tin-scrap."

A meeting of the Branch was held on December 11, 1912. The chairman, Professor H. C. Bartholomew, gave a lecture on " Recent Developments in Street Railway Practise."

The chairman announced the appointment of the following membership committee: Messrs. D. W. Hoot, F. Roberson and A. E. Hartung.

UNIVERSITY OF IOWA

A meeting of the University of Iowa Branch was held on January 14, when Mr. G. K. Pierce spoke on the subject of " The Electric Power Plant of the Hart-Parr Company at Charles City, Iowa."

UNIVERSITY OF KANSAS

The University of Kansas Branch held a meeting on December 18, 1912, when Messrs. C. F. Hanson and T. A. E. Belt reported on the inspection trip to the Mississippi River Power Company's plant at Keokuk, Iowa. Mr. Michael Lynch, 1911, now in the employ of the Westinghouse Electric and Manufacturing Company, gave a talk on the apprenticeship course of that company. Mr. F. D. Phillips, 1907, employed by the General Electric Company, and Mr. F. P. Ogden, 1911, in the service of the Bell Telephone Company of Topeka, Kansas, as traffic manager, also gave experience talks.

A meeting of the Branch was held on January 8, when Mr. F. H. Hanson of the Public Utilities Commission of the State of Kansas made an address on " The Regulation of Public Utilities."

At the meeting of the Branch on January 29, Professor A. H. Sluss of the mechanical engineering department spoke on " The Loss in the Heat Value of Coal Due to Handling and Weathering." Messrs. J. Segel and A. J. Fecht, 1914, spoke on " The Development of Mechanical and Electrical Industries During 1912."

KANSAS STATE AGRICULTURAL COLLEGE

A meeting of the Kansas State Agricultural College Branch was held on

January 17, when Mr. C. A. Leech was elected chairman for the year. A program committee was appointed, and a number of applications for membership presented.

University of Kentucky

A meeting of the State University of Kentucky Branch was held on January 24. Three papers recently published in the Proceedings were presented, as follows: *Measuring Stray Currents in Underground Pipes*, Carl Hering; *A Visit to the Panama Canal*, E. D. Edmonston; and *Electrolytic Corrosion of Iron by Direct Current in Street Soil*, A. F. Ganz; presented, respectively, by Messrs. T. C. Lewis, F. J. Forsyth, and J. F. Hall.

Lafayette College

A meeting of the Lafayette College Branch was held on January 21. Mr. Hay of the senior class presented a paper on "Interpoles and Interpole Machines," taking up the operating characteristics of interpole machines, and the effects of brush shift with attendant difficulties in paralleling interpole generators. Dr. Rood took up the question of increased leakage factor and the magnetic densities of the interpoles.

Mr. Davidson of the junior class read a paper on "Recent Tests of Insulators and Terminals," a resume of the exhaustive tests and efforts to standardize a series of tests on insulators. Dr. Rood described the types of terminals at present in use, with particular reference to their service at high potentials.

Mr. Simmons of the junior class read a paper on "Vehicle Dynamos," dealing with the types of machines used to charge automobile batteries, and take care of general lighting on cars. Performance curves of different makes were shown.

At the meeting of the Branch on January 28, Mr. E. J. Fager of the senior class described the Keokuk hydroelectric plant on the Mississippi with the aid of drawings and photographs. Mr. Kolb of the junior class presented a paper on "The History and Development of the Transformer," from Faraday's original transformer to the present types. Mr. Ellis of the junior class spoke on "The Use of Synchronous Condensers with Automatic Voltage Regulators" for constant e.m.f. and the correction of power factor. This subject elicited considerable discussion.

A meeting of the Branch was held on February 4. Mr. Clymer of the junior class presented the subject of "The Grounded Neutral." Examples of the practise of large companies were used to show when and why the neutral should be grounded in high-tension alternating-current work. The general discussion which followed emphasized the lack of uniformity in this regard. Mr. Heydt of the senior class read a paper descriptive of "The Snoqualmie Plant," with lantern slides illustrating the features of this unusual subterranean hydroelectric plant. Mr. Maue of the senior class gave a talk on "Commutator Slotting" as a means of improving commutation.

Lehigh University

The last meeting of the Lehigh University Branch for the year 1912 was held in the physics lecture room on December 17.

The entire evening was devoted to a paper on "High-Frequency Electric Oscillations" by Professor S. S. Seyfert of the electrical department. Professor Seyfert first discussed the theory underlying the production of high frequency and its dependence upon the induction and capacity of an oscillating closed circuit in accordance with the well-known formula, $f = \frac{1}{2} \pi \sqrt{LC}$, where f is the frequency of oscillation in cycles per second and L and C are the inductance and capacity of the closed circuit.

With the aid of Professor Franklin a number of interesting experiments were performed, the first of which embodied the production of electric waves by means of the Hertz oscillator, followed by experimental demonstrations of stationary electric waves on a pair of straight wires by the Lecher and Seibt methods. The latter method proved very successful, the frequency of the oscillations being such that three distinct voltage nodes were obtained on a comparatively short length of the "transmission line." The effects on voltage distribution of an open-ended and a short-circuited transmission line were likewise demonstrated by this method.

Professor Seyfert discussed the oscillation transformer with its application to wireless telegraphy. The difference between the quenched spark and the sustained spark was next discussed and illustrated; the former being used in wireless telegraphy and the latter, produced by the Poulsen arc or by the Chaffee arc, being used in wireless telephony.

An interesting demonstration was given of the use of the Brown tube as a high-frequency oscillograph.

The last and probably the most spectacular experiment of the evening was that illustrating the operation of the Tesla transformer. The primary consisted of three turns of heavy cable across which an e.m.f. of 50,000 volts was impressed, and the secondary was an air coil of about 315 turns.

The meeting of the Branch on January 14 was held at the home of Dr. H. S. Drinker. The first paper, entitled "Life in Schenectady," was read by Chairman W. J. Dugan. This paper was written by Mr. H. W. Porter, 1912, who is at present employed as a tester at the Schenectady works of the General Electric Company, and explained the working of the company's student apprentice course.

Mr. H. W. Motter presented a paper on "Elementary Principles of the Storage Battery," and Mr. E. F. Weaver read a paper describing the senior electrical inspection trip. The paper gave an outline of the six-day trip, with a brief description of the large manufacturing, testing and generating plants visited, and cited the salient features of practise in regard to equipment, construction and operation as found in them.

UNIVERSITY OF MAINE

The meeting of the University of Maine Branch on January 8 was addressed by Professor W. E. Barrows, head of the electrical engineering department, on the subject "New Lamps and New Methods of Illumination." After giving a short sketch of the lighting industry of to-day, Professor Barrows took up several of the more recent types of illuminants such as the Moore light, luminous and flaming arc lamps, and the quartz and neon tubes.

UNIVERSITY OF MISSOURI

At the meeting of the University of Missouri Branch on January 13, the subject of discussion was "Making a Small Power Plant Pay." Mr. F. G. Beckman opened the subject with a talk on management and cost-keeping, saying that poor record and cost-keeping was a vital reason for the lack of success of many small plants. Mr. J. H. Spurgeon discussed the distribution system, showing the considerations that determine the design of the feeder lines. He said that much power was wasted in some systems by using numerous small transformers instead of combining the loads and using larger transformers. Mr. F. H. Templeton took up the question of improving load conditions, giving some interesting examples of skilful advertising and educational campaigns.

MONTANA STATE COLLEGE

The meeting of the Montana State College Branch on January 17 was devoted to a discussion of the two papers presented at a recent Institute meeting in New York, *High-Frequency Tests of Line Insulators* and *Comparative Tests on High-Tension Suspension Insulators.* A thorough abstract of the first paper was read by Mr. Max Kenk. Mr. L. Wylie and Professor J. A. Thaler discussed the second paper. Professor Thaler also gave an actual demonstration of wet and dry flash-over and puncture tests. The second paper was of particular interest to the members of this Branch for the reason that the same types of insulators (styled A, C, D and E in the paper) had been tested in the college laboratory some three years ago for the purpose of selecting a suitable type of insulator for a 100,000-volt transmission line between Great Falls and Butte. From these tests the same insulator was chosen, and is now in use on the line, as was found to give the best results in the comparative tests described in Mr. Sothman's paper.

UNIVERSITY OF NEBRASKA

The University of Nebraska Branch held a meeting on January 16, when Dean O. V. P. Stout of the college of engineering spoke on the engineering, construction, and operation of hydro-electric power plants, with particular reference to the features which appertain to technical hydraulics. The principles of design and construction of dams, retaining walls, and closed or open conduits, were outlined, with special reference to the graphical solution of such problems.

A business meeting of the Branch was held on January 21, for the election of officers. The officers elected for the coming six months were as follows: Chairman, Professor Olin J. Ferguson; corresponding secretary, Professor V. L. Hollister; student chairman, Mr. G. A. Walker; student secretary, Mr. L. P. Arms, and student treasurer, Mr. C. O. Martz.

NEW HAMPSHIRE COLLEGE

At the meeting of the New Hampshire College Branch held on January 6, Dr. Louis C. Lowenstein of the turbine department of the General Electric Company at Lynn, Mass., gave a talk on " Centrifugal Air Compressors." After giving a brief history of the compressors as manufactured in Europe and the United States, he described the most modern types, with the aid of lantern slides. Dr. Lowenstein emphasized the great decrease in floor space and head-room required for the centrifugal type as compared with the reciprocating compressor, and expressed the belief that within a few years the centrifugal type would replace the older style, as there was no limit to its capacity.

At the meeting of the Branch on January 20, the speaker was Mr. L. N. Barrett of the senior class, whose subject was " Electric Vehicles." After outlining the development of the electric automobile Mr. Barrett gave data demonstrating the advantages of the electric type over gasoline and steam vehicles for runs of comparatively short radius. Stereopticon views showed several different kinds of trucks and the well-known makes of storage batteries.

NORTH CAROLINA COLLEGE

A meeting of the North Carolina College Branch was held on January 16, when Mr. C. A. Bache read an abstract of the recent Institute paper *The Economical Speed Control of Alternating-Current Motors Driving Rolling Mills*, by F. W. Meyer and Wilfred Sykes. A short discussion followed the abstract.

At a meeting of the Branch held on January 27, Mr. P. B. Fenbee gave a talk on "The Development of the Southern Power Company." Mr. W. R. Clements read an abstract of an article on the treatment of electric shocks from the *Electrical Review*.

OHIO NORTHERN UNIVERSITY

On December 16, 1912, the members of the Ohio Northern University Branch started on an inspection trip to Pittsburgh, Pa. That evening the party visited the Cement Show in Pittsburgh. The next day was spent at the works of the Westinghouse Machine Company and the Westinghouse Electric and

Manufacturing Company. The morning of the 18th was devoted to the Jones and Laughlin Company's steel mills, and the afternoon to the Carnegie Institute and Technical School. In the evening the party was entertained at a smoker by the Ohio Northern University alumni. Among other places visited the next day were the plants of the Universal Portland Cement Company and the Mesta Machine Company.

The meeting of the Branch on January 7 was devoted to discussion of the things seen on the inspection trip. Mr. George Boesger and Mr. D. W. Yambert discussed respectively the visit to the Jones and Laughlin Company's steel plant, and the Westinghouse works.

On January 29 a meeting of the Branch was held, when Mr. W. H. Kroger gave a talk on " Comparative Methods of Wiring in Germany, France and the United States," and Mr. G. H. Bull discussed " The Advancement in the Electrical Industry during the Past Year."

Ohio State University

A meeting of the Ohio State University Branch was held on December 12, when Professor Hammond of the department of economics spoke on the subject of " Corporation Finance."

Oklahoma A. & M. College

At the meeting of the Oklahoma Agricultural and Mechanical College Branch, held on December 5, 1912, three Institute papers were reviewed—*An Alternator for 100,000 Cycles*, E. F. W. Alexanderson; *Some Problems of High-Voltage Transmission*, C. P. Steinmetz; and *The Use of Reactance in Transformers*, W. S. Moody.

A meeting of the Branch was held on January 18, when the following papers were taken up: *Electrical Operation of the West Jersey and Seashore Railroad*, B. F. Wood; *Oil-Break Circuit Breakers*, E. B. Merriam; *The Electric Strength of Air*, J. B. Whitehead; " Thury Continuous-Current Series System of Power Transmission," Alfred Still; " History of Incandescent Lamp Manufacturer," Henry Schroeder, and *The Regulation of Distributing Transformers*, C. E. Allen.

At the meeting of the Branch on February1 several papers were reviewed, as follows: *Voltage Regulation of Generators*, H. A. Laycock; " Electric Ship Propulsion," W. T. Donnelly and G. A. Orrock; *The Economical Speed Control of Alternating-Current Motors Driving Rolling Mills*, F. W. Meyer and Wilfred Sykes; " Abnormal Strains in Transformers," C. P. Steinmetz; and two papers on " The Electric Operation of the Panama Canal," and " Hydroelectric Power Development in Sweden."

University of Oklahoma

A meeting of the University of Oklahoma Branch was held on December 11, 1912, when the Branch voted to accept the constitution and by-laws as reported by the committee appointed for that purpose. Professor H. V. Bozell than made an address on " The A. I. E. E. and Its Work." Following this Mr. D. A. Ballard discussed the recent Institute paper *Metallic Tungsten and Some of Its Applications*. Mr. V. E. Alden, 1911, who is at present employed in the transformer department of the Westinghouse Electric and Manufacturing Company, gave a talk on his work with that company.

The second regular meeting of the Branch was held on January 15. Mr. R. W. Stinson presented a review of current literature in the electrical field appearing during the preceding month. Mr. H. T. Asbury reviewed and discussed the paper by Mr. F. C. E. Burnett, on *Electricity in the Portland Cement Industry*, which was printed in the September, 1912, PROCEEDINGS. Professor H. B. Dwight than made an address on " Irrigation in Oklahoma."

UNIVERSITY OF OREGON

At the meeting of the University of Oregon Branch on December 10, Mr. C. H. Myers was elected to fill a vacancy on the executive committee.

Mr. F. C. Burke, of the Oregon Power Company, presented a paper on "Transmission Line Construction." The speaker described some methods that are used in assembling and distributing materials, and in erecting the line. The need of properly guying the line was emphasized, especially in a region like the Willamette Valley, where the soil becomes thoroughly water-soaked. Transpositions, crossings, and corners were illustrated by sketches and blue prints. Mr. Burke considered a well-grounded guard wire, of ample size, a great protection from lightning.

Mr. C. H. Myers gave a brief exposition of the catenary construction. Its advantages were pointed out and the different combinations of steel and copper used in its construction were described.

A meeting of the Branch was held on January 16. Professor A. F. Reddie gave an informal talk on the preparation and delivery of a public address. Professor Reddie stated that the man who wishes to deliver an effective speech should appeal to the reason and not to the feeling of his audience. The speaker should have a desire to give, to impart something of value. The preparation of a public address should command the same painstaking care that the engineer gives to his technical studies.

Mr. C. R. Reid gave an abstract of the Institute paper on *High-Speed Turbo-Alternators—Designs and Limitations*, by B. G. Lamme, published in the January PROCEEDINGS.

OREGON AGRICULTURAL COLLEGE

A meeting of the Oregon Agricultural College Branch was held on December 19, 1912. The speakers of the evening were Mr. L. Read, who gave an illustrated lecture on "The Bull Run Power Plant", and Mr. Rosencrantz, whose subject was "The Testing of Water Turbines at the Bull Run Power Plant." Both speakers gave a detailed account of the efficiency tests recently carried out by the Portland Railway, Light and Power Company, at its plant at Bull Run, Ore.

PENNSYLVANIA STATE COLLEGE

A meeting of the Pennsylvania State College Branch was held on October 9, 1912, when plans were made for the season, and Mr. Markle of the electrical department spoke on the advantages of membership in the Branch.

On November 11, Mr. G. Paxson Murphy of the senior class addressed the Branch on his experiences in connection with work last summer in the generating department of the Philadelphia Electric Company.

At the meeting on December 4, officers for the ensuing semester were elected, as follows: Chairman, I. S. Nippes; secretary, J. H. Burgess. Mr. C. C. Goldenberg of the senior class spoke on the subject of "Telephony," referring particularly to the operation of exchanges in Atlantic City, N. J.

A meeting of the Branch was held on January 15, when Mr. Markle gave a talk on "Illumination," and Mr. Bovar spoke on the advantages of the student apprentice course of the Westinghouse Electric and Manufacturing Company.

ROSE POLYTECHNIC INSTITUTE

The monthly meeting of the Rose Polytechnic Institute Branch was held on December 5, 1912, at the Heminway Memorial Building. Mr. Reese presented the Institute paper, ***The Effect of Temperature on Hysteresis Losses in Iron and Steel***, which appeared in the October, 1912, PROCEEDINGS. A lengthy discussion of the subject ensued.

The next monthly meeting of the Branch was held on the evening of January 16 at the physical laboratory. The recent Institute papers, ***High-Frequency Tests of Line Insulators*** and ***Comparative Tests on High-Tension Suspension Insulators***, were read by Messrs. Ostrander and Smith, respectively. Various kinds of porcelain and glass insulators were tested out upon high-voltage lines, as were also glass plates, tubes and bottles.

STANFORD UNIVERSITY

A meeting of the Stanford University Branch was held on December 6, 1912. Mr. Gustav Wade resigned the chairmanship of the Branch, due to the fact that he would not be at the University after the first of the year, and Mr. Linford C. Lull, Jr., was elected chairman in his place. Seven new members were also elected.

This was the occasion of the semester banquet, at the Stanford Inn. Mr. Gustav Wade was toastmaster. Talks were given by Professor Harris J. Ryan, Mr. Walter J. Dodge, secretary of the Branch, and Professor William F. Durand, professor of mechanical engineering.

SYRACUSE UNIVERSITY

A meeting of the Syracuse University Branch was held on February 5, when the matter of a program for the current half year was discussed. Fifteen applications for student membership were received at the meeting. Dean W. P. Graham spoke briefly on some points in Mr. B. G. Lamme's Institute paper on ***High-Speed Turbo-Alternators—Designs and Limitations.***

UNIVERSITY OF TEXAS

On December 13, 1912, the University of Texas Branch met for the election of officers, which resulted as follows: Chairman, J. A. Correll; secretary-treasurer, Joseph W. Ramsay; executive committee, W. E. Keck, J. W. Lovli, and J. W. Loef.

A meeting of the Branch was held on January 17, when Mr. M. C. Crawford presented a paper on "The Development and Use of the Modern Incandescent Lamp," and Mr. J. W. Loef reviewed the recent Institute paper ***The Effect of Temperature on the Magnetic Properties of Iron and Steel.***

AGRICULTURAL AND MECHANICAL COLLEGE OF TEXAS

A meeting of the Agricultural and Mechanical College of Texas Branch was held on December 2, 1912. The first speaker was Mr. H. C. von Rosenberg, who made a comparison of aluminum and mercury-arc rectifiers. Professor J. F. Lear then gave a talk on "The Unity Power Factor Motor." Programs of the work of the Branch for the coming year had been printed and were distributed among the members.

At the meeting of the Branch on December 13, Mr. J. F. Brown gave a talk on his experiences in the operation of a gas-electric plant in a cement mill. Professor O. B. Wooten then addressed the Branch upon the engineering experiment work at the University of Illinois, where he had spent a year in research work.

On January 13 the Branch held its first meeting of the new year. Mr. A. J. Neff, a post-graduate in the mechanical engineering department, spoke on the subject of "Steam Turbines." After discussing the general principles of the steam turbine, Mr. Neff took up in detail the De Laval, Curtis-Riedler, Curtis, Parsons, and Westinghouse-Parsons types, describing them with the aid of lantern slides. The speaker mentioned the growing demand for low-pressure turbines to utilize to the utmost the work in the steam. He described different types of reduction gearing, and mentioned the recent Tesla turbine which utilizes only the viscosity of the expanding steam.

Mr. R. W. Nolte of the senior class

was the next speaker, and described his recent trip to the Panama Canal.

A special meeting of the Branch was held on January 17, when Mr. F. G. Cox, of the Otis Elevator Company of Dallas, Texas, gave a stereopticon lecture on elevators and their development in recent years. Mr. Cox said that the first type to be successfully used, the hydraulic plunger type, had reached its limit at a height of travel of 208 ft. (63.4 m.). With the increase in height of buildings and the demand for high-speed service, the hydraulic elevator went out of extensive use, and was superseded by the electric elevator. The demand for elevator service was shown by the statement that in New York City there are 13,000 freight elevators and 11,000 passenger elevators, carrying seven to eight million passengers per day.

The speaker described the machine designed by Mr. Frank J. Sprague, a horizontal machine consisting of two sheaves, one stationary, the other movable, worm-driven by an electric motor, with a brake on the end of the motor shaft. This design was later modified in various ways. The speaker said that the modern traction type attained a speed of nearly 700 ft. (213 m.) per min. He stated that direct-current motors were principally used, and that the alternating-current motor was not yet adapted for a speed of elevator travel greater than 250 ft. (76 m.) per min. Mr. Cox described various safety devices, and signal systems to reduce the time lost in stopping for passengers.

The lecture was held under the auspices of the Branch, but all the engineering students had been invited, and there was an attendance of some two hundred.

THROOP POLYTECHNIC INSTITUTE

A meeting of the Throop Polytechnic Institute Branch was held on November 22, 1912, when three of the members spoke on subjects relating to their engineering experiences, as follows: "Cable Installation," Mr. Morse; "Troubles of a Trouble Man," Mr. Wells; "Hydraulic Mining in California," Mr. Call.

At the meeting of the Branch on December 20, Mr. Benjamin De Lanty presented a paper on "Making Joints in Electrical Conductors."

A meeting of the Branch was held on January 24, when the following papers were read: "Present Tendencies in Steam Power Plant Design," presented by Mr. H. S. Wood; "The Keokuk Power Development," Mr. Louis J. Koch; "Diesel Engines for Ship Propulsion," Mr. R. W. Parkinson, "Electric Ship Propulsion," Mr. Ray Gerhart.

UNIVERSITY OF VIRGINIA

A meeting of the University of Virginia Branch was held on January 13, in the mechanical laboratory. Dr. Carl Hering presented a paper on "Electrochemical Engineering" After discussing the fundamental relations existing in electrochemical problems and reviewing the activities in this line of work in the past, Dr. Hering outlined several interesting problems for future solution. Diagrams were presented showing the relative costs of fuel and electric heating, and various types of electric furnaces were described.

WASHINGTON UNIVERSITY

A meeting of the Washington University Branch, St. Louis, Mo., was held on December 6, 1912. Two papers were read by students of the university. Mr. F. A. Kohlmeyer presented a paper on "Scientific Shop Management." Mr. C. E. Wright's paper was "The Power Plants and Power Distribution of the Illinois Traction System," describing the present operating methods and some problems that had recently come up. Schematic wiring diagrams of the power stations and substations were presented, and a few calculations of transient voltages on the transmission lines.

UNIVERSITY OF WASHINGTON

"High-Voltage Transmission" was the subject of a paper presented before the University of Washington Branch, Seattle, Wash., by Mr. Magnus T. Crawford, superintendent of transmission of the Puget Sound Traction, Light and Power Company on January 23. This was the initial meeting of this newly organized Branch of the Institute.

STATE COLLEGE OF WASHINGTON

At the meeting of the State College of Washington Branch, Pullman, Wash., on December 10, 1912, Mr. P. H. Neuman of the senior electrical class presented an abstract of the Institute paper *The Use of Reactance in Transformers,* by W. S. Moody.

A meeting of the Branch was held on December 17, when Mr. J. C. Beckman of the senior class presented a paper entitled "Testing the Little Falls Power Plant of the Washington Water Power Company." Mr. Beckman was employed by the company at the time these tests were made and assisted in them. He gave a detailed account, illustrated with many photographs he had taken of the work.

At the Branch meeting on January 7, Mr. James McNair of the junior class presented a paper on "The Advantages of Isolated Plants as Compared with Central Stations for the Production of Power." Mr. McNair, referring to several recently published papers, and to figures which he had obtained, argued that, for many cases not now accepted, an isolated plant could produce the power more cheaply. It was announced that the other side of the question would be presented at a later meeting by another member of the class.

WORCESTER POLYTECHNIC INSTITUTE

A meeting of the Worcester Polytechnic Institute Branch was held on January 10, when Mr. A. H. Abbott, sales agent of the Boston office of the General Electric Company, lectured on "Ozonators." The speaker discussed the theory of the production of ozone, and described the construction and operation of one type of apparatus. He mentioned what had been done abroad in water purification, and spoke of the therapeutic possibilities of the ozonator. A general discussion followed the lecture, in which Mr. Abbott answered questions.

YALE UNIVERSITY

"Electric Development in the West—Hydroelectric Plants and Mines," was the subject of a talk by Mr. R. H. Parker, manager of the New Haven office of the General Electric Company, at a meeting of the Yale University Branch on January 29. Mr. Parker, who until recently has been engaged in electrical work in Utah, described briefly the distinctive features of the important plants in the western part of the country, beginning with the first development using high-tension transmission—40,000 volts— put into operation in 1893. He pointed out the rapid advances made since that time and showed to what an extent electricity is used. Regarding the comparative cost of power from hydroelectric plants and steam plants, he refuted the popular opinion that water power is necessarily cheap, stating that the cost of the dam, penstock, etc., together with the cost and upkeep expense of the generally very long transmission line, usually make the price of water power about the same as that of steam power. He admitted, however, that there are striking exceptions; for instance, a development made by the government in Idaho is delivering energy at such cheap rates that new houses in the vicinity are being put up without chimneys, depending entirely upon electricity for heat.

The speaker also mentioned many of the uses of electricity in mines and showed pictures of mine hoists, locomotives, and an unusual method of lighting by means of searchlights. He spoke of a proposed electrification of a railroad down the mountainside from a mine; it is possible, on this road, not only to use no net energy, but, by regenerative braking, to assist the power plant in furnishing power to a mill at the lower end of the line.

Death of John Fritz

On February 13, 1913, at his home in Bethlehem, Pa., occurred the death of John Fritz, the ironmaster, in his ninety-first year. He was a man who received not only honor for his achievements in the development of the iron and steel industry, but friendship and affection called forth by his fine qualities of character. He was a past president of both the American Institute of Mining Engineers and the American Society of Mechanical Engineers, and an honorary member of the American Society of Civil Engineers and of the American Iron and Steel Institute, and honorary vice-president for life of the Iron and Steel Institute, of London.

John Fritz was born in Chester County, Pa., in 1822. He left his father's farm at the age of sixteen to secure employment in a country machine shop at Parkesburg, Pa. This was the first step toward his long and distinguished career in the iron and steel industry. In 1844 he went to Norristown, Pa., to the rolling mill of Moore and Hooven. It was not long before he became superintendent of this plant. Further steps were the management of the Reeves, Abbott and Company blast furnace near Philadelphia, and his work as general superintendent of the Cambria Iron Works at Johnstown. Here he invented the three-high rail mill, and made many other improvements.

In July, 1860, he became general superintendent and chief engineer of the Bethlehem Iron Company, and built the great Bethlehem works. He was in active service with the company until 1892, but his withdrawal from manufacturing was not retirement, for he continued to be engaged as consulting engineer in connection with many important undertakings.

The eightieth birthday of Mr. Fritz was celebrated by a banquet in New York on October 31, 1902, which marked the foundation in his honor, of the John Fritz Gold Medal by the United Engineering Societies, to be awarded for scientific or industrial achievement. On this occasion Mr. Fritz was presented with a bronze cast of the medal as modeled by the artist. Lord Kelvin was the first recipient of the medal. Those who have since received this honor are George Westinghouse, Alexander Graham Bell, Thomas Alva Edison, Charles T. Porter, Alfred Noble, Sir William Henry White and Captain Robert Woolston Hunt.

Obituary

FELIX BENEDICT HERZOG, PH.D., died at the Roosevelt Hospital, New York City, April 21, 1912, following an operation for an internal disorder with which he had been afflicted. Dr. Herzog was born in New York City December 27, 1859, and was graduated from Columbia University in 1881 with the degree of A. B., LL. B., 1882, A. M., Ph. D.,1883. He was elected an Associate of the A. I. E. E., May 24, 1887, and transferred to the grade of Member July 12, 1887. He was elected a Manager the same year, serving until 1892. He was a prolific inventor, especially in the field of signaling devices, and at the time of his death was president of the Herzog Teleseme Company. He was active in art matters, and as a painter was a pupil of Rondel. He was also interested in photography, both technical and artistic, and was an inventor of photographic appliances. While his devotion to art had in a measure taken him out of the electrical field, he will be remembered as taking an active part in the earlier work of the Institute.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

TO JANUARY 15

Die Bedienung und Wartung Elektrischer Anlagen und Maschinen von Joseph Spennrath. Ed. 2, by Frz. Menge. Berlin, 1912. (Purchase.)

Calculs Techniques et Economiques des Lignes de Transport et de Distribution d'Energie Electrique. By C. LeRoy. Première partie Paris. A. Herman et Fils, 1912. (Gift of publishers.)

Cleveland Engineering Society. Annual Register and Constitution, July 1, 1912. Cleveland, 1912. (Exchange.)

Currents of High Potential of High and Other Frequencies. Ed. 2. By W. B. Snow. New York, 1911. (Purchase.)

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Boston Feb. 13, '03	Fred. P. Valentine.	Leavitt L. Edgar, 39 Boylston St., Boston, Mass.
Chicago 1893	Ralph H. Rice.	E. W. Allen, 1028 Monadnock Building, Chicago, Ill.
Cleveland Sept. 27, '07	E. J. Edwards.	R. B. Chillas, Jr., National Carbon Co., Cleveland, Ohio.
Detroit-Ann Arbor Jan. 13, '11	J. J Woolfenden.	Ray K. Holland, Cornwall Building, Ann Arbor, Mich.
Fort Wayne Aug. 14, '08	T. W. Behan.	P. H. Haselton, Fort Wayne Electric Works. Ft. Wayne, Ind.
Indianapolis-Lafayette Jan. 12, '12	O. S. More.	Charles A. Tripp, 710 Majestic Building, Indianapolis, Ind.
Ithaca Oct. 15, '02	E. L. Nichols.	George S. Macomber, Cornell University, Ithaca, N. Y.
Los Angeles May 19, '08	G. A. Damon.	E. R. Northmore, Los Angeles Gas and Electric Company, Los Angeles, Cal.
Lynn Aug. 22, '11	W. A. Hall.	E. R. Berry, General Electric Co., Lynn, Mass.
Madison Jan. 8, '09	E. H. Kifer.	F. A. Kartak, Univ. of Wisconsin, Madison, Wis.
Mexico Dec. 13, '07	H. S. Foley.	James Carson, Mexican Light and Power Company, Mexico City, Mexico
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Philadelphia Feb. 18, '03	H. A. Hornor.	H. F. Sanville, 1326 Chestnut St., Philadelphia, Pa.
Pittsburgh Oct. 13, '02	E. L. Farrar,	M. C. Turpin, Department of Publicity, W. E. and M. Company, Pittsburgh, Pa.
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Schenectady Jan. 26, '03	John B. Taylor.	J. A. Dewhurst, Gen. Elec. Co., Schenectady, N. Y.
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St. Louis Jan. 14, '03	Joseph A. Osborn.	F. J. Bullivant, 6400 Plymouth Avenue, St. Louis, Mo.
Toledo June 3, '07	George E. Kirk.	Max Neuber, Care of Cohen, Friedlander & Martin, Toledo, O.
Toronto Sept. 30, '03	F. A. Gaby.	H. T. Case, Continental Life Bldg., Toronto, Ont.
Urbana Nov. 25, '02	A. M. Buck.	F. G. Willson, University of Illinois, Urbana, Ill.
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Arkansas, Univ. of......Mar. 25, '04	W. B. Stelzner.	G. W. Watkins, Room 25, Buchanan Hall, Fayetteville, Ark.
Armour Institute........Feb. 26, '04	W. Fryberg.	R. L. Walsh, Armour Inst. Tech., Chicago, Ill.
Bucknell University.....May 17, '10	E. M. Richards.	Robert L. Rooke, Bucknell University, Lewisburg, Pa.
California Univ. of......Feb. 9, '12	Charles Grunsky.	C. I. Kephart, University of California, Berkeley, Cal.
Cincinnati. Univ. of......Apr. 10, '08		
Clemson Agricultural College..................Nov. 8, '12	J. H. Kangeter.	H. J. Bomar, Clemson College, S. C.
Colorado State Agricultural College.........Feb. 11, '10	Robert O. Sewell.	R. K. Havighorst, Colorado State Agricultural College, Fort Collins, Colo
Colorado, Univ. of.......Dec. 16, '04	Harry McKinney.	Seizo Uyeda, 1075 12th St., Boulder, Colo.
Highland Park College..Oct. 11, '12	J. W. Spooner.	Ralph R. Chatterton, Highland Park College, Des Moines, Iowa
Iowa State College......Apr. 15, '03	H.C.Bartholomew	F. A. Robbins, Iowa State College, Ames, Iowa.
Iowa, Univ. of..........May 18, '09	L. F. Hatz.	A. H. Ford. University of Iowa, Iowa City, Ia.
Kansas State Agr. Col....Jan. 10, '08	C. A. Leech.	W. C. Lane, Kansas State Agric. Col., Manhattan, Kan.
Kansas, Univ. of........Mar. 18, '08	S. S. Schooley.	A. J. Fecht, Univ. of Kansas, Lawrence, Kan.
Kentucky, State Univ. of Oct. 14, '10	R. B. Pogue.	W. M. Lane, 216 Rose Street, Lexington, Ky.
Lafayette College........Apr. 5, '12	F. W. Maue.	W. O. Hay, Jr. Lafayette College, Easton, Pa.
Lehigh University.......Oct. 15, '02	W. J. Dugan.	E. F. Weaver, Lehigh University, S. Bethelhem, Pa.
Lewis Institute..........Nov. 8, '07	Ralph Kilner.	A. H. Fensholt, Lewis Institute, Chicago, Ill.
Maine, Univ. of.........Dec. 26, '06	Howard O.Burgess	J. Larcom Ober, S. A. E. House, Orono, Maine.
Michigan, Univ. of......Mar. 25, '04	Ward F. Davidson	Edward A. Roeser. Univ. of Michigan, Ann Arbor, Mich.
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Ohio Northern Univ.....Feb. 9, '12	F. M. Billhimer.	D. W. Yambert, Ohio Northern University, Ada, Ohio.
Ohio State Univ........Dec. 20, '02	R. E. Kinkead.	T. O. Farmer, Ohio State Univ., Columbus, Ohio.
Oklahoma Agricultural and Mech. Coll.......Oct. 13, '11	A. P. Little,	J. W. Harvey, 416 Hester Street, Stillwater, Okla.
Oklahoma, Univ. of.....Oct. 11, '12	David E.Renshaw	Leo H. Gorton, 526 UniversityBoulevard,Norman,Okla.
Oregon Agr. Col........Mar. 24, '08	Lance Read.	Charles E. Oakes, Oregon Agric. Col., Corvallis, Ore.
Oregon, Univ. of........Nov. 11, '10	R. H. Dearborn.	C. R. Reid, Univ. of Oregon, Eugene, Oregon.
Penn State College......Dec. 20, '02	K. P. Fuhrman.	I. S. Nippes, Pennsylvania State College, State College, Pa.
Purdue Univ............Jan. 26, '03	C. F. Harding.	A. N. Topping, Purdue University, Lafayette, Ind.
Rensselaer Poly. Inst..Nov. 12, '09	E. D. N. Sc ulte.	W. J. Williams, Rensselaer Poly. Institute, Troy, N. Y
Rose Polytechnic Inst...Nov. 10, '11	S. Irwin Stocking.	Joseph E. O'Connell, 457 N. 8th Street, Terre Haute, Ind.
Stanford Univ..........Dec. 13, '07	Linford C. Lull, Jr.	Walter J. Dodge, Stanford University, California.
Syracuse Univ..........Feb. 24, '05	W. P. Graham.	R. A. Porter, Syracuse University, Syracuse, N. Y.
Texas, Univ. of.........Feb. 14, '08	J. A. Correll.	Joseph W. Ramsay, University of Texas, Austin, Tex.
Throop Poly. Inst.......Oct. 14, '10	Ray Gerhart.	R. W. Parkinson, Throop Poly. Institute, Pasadena, Cal.
Univ. of Washington.. .Dec. 13, '12	George Tripple.	S. R. Shave, Univ. of Washington, Seattle, Wash.
Vermont, Univ. of.......Nov. 11, '10	Walter L. Upson.	O. Krupp, 65 North Bend St., Burlington, Vt.
Virginia, Univ. of........Feb. 9, '12	Walter S.Rodman	Henry Woodma [illegible] A. X. P. House, University,Virginia.
Wash., State Coll. of....Dec. 13, '07	M. K. Akers.	H. V. Carpenter, State Col. of Wash., Pullman, Wash.
Washington Univ.......Feb. 26, '04	C. E. Wright.	A. S. Blaattermn, Washington University, St. Louis, Mo
Worcester Poly. Inst...Mar. 25, '04	Harry B. Lindsay.	George I. Gilchrest, Worcester Poly. Inst., Worcester, Mass.
Yale University.........Oct. 13, '11	R.H. Willard, Jr.	M. R. Wibberley, 136 Vanderbilt-Scientific, New Haven, Conn.

Total, 46.

SECTION II

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of the
American Institute
of
Electrical Engineers

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HIGH SPEED TURBO-ALTERNATORS—DESIGNS AND LIMITATIONS

BY

B. G. LAMME

Presented under the auspices of the

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HIGH SPEED TURBO-ALTERNATORS—DESIGNS AND LIMITATIONS

BY B. G. LAMME

ABSTRACT OF PAPER

The paper discusses the design of turbo-alternators with reference to the limitations imposed by very high rotative speeds and large capacities.

Bolted-on rotor shafts have superseded through-shafts for very high speeds, and both the radial-slot and the parallel-slot types of rotors have inherent advantages for machines of certain capacities. Ventilation is difficult on account of the large total loss which occurs in a limited space, requiring very large volumes of cooling air at very high velocities. Various ventilating systems are described, and the effects of temperature limitations upon the design are discussed.

Insulating materials are considered with reference to their mechanical strength and resistance to heat. The use of mica in various forms has solved many difficulties due to high temperature and to static discharges.

The copper and iron losses of these units are analyzed; the total losses are no greater than those of low-speed units of corresponding capacity. Protection against fire within the machine is most effectively provided by doors or valves, entirely cutting off the interior of the machine from the outside air. The regulation is sacrificed to some extent, in order to limit short circuit current, by making the armature reactance as high as the design will permit.

A paper to be presented at the 279th Meeting of the American Institute of Electrical Engineers, New York, January 10, 1913.

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(*Subject to final revision for the Transactions.*)

HIGH SPEED TURBO-ALTERNATORS—DESIGNS AND LIMITATIONS

BY B. G. LAMME

The real problems in the design of turbo-alternators did not really develop until the high-speed, large capacity units came into demand. In the earlier work, the difficulties in design were mostly those due to lack of experience and to insufficient knowledge of the possibilities of materials, etc. As more data were obtained, the speeds and capacities were gradually increased until with the present large capacities and high speeds, a number of conditions are encountered which may be considered as true physical limitations.

The principal difficulties in the design of the earlier machines were found in the permissible weight which could be carried by bearings, undue noise due to the open construction of the machines, and the troubles incident to the through-shaft construction of the rotor.

The bearing problem was eliminated by securing more complete data, which showed that the possibilities in this feature had hardly been touched upon.

The solution of the noise problem was largely one of enclosing the machine without interfering with the ventilation. In doing this, the noise problem was practically eliminated, but the greater problem of ventilation then developed.

In overcoming the difficulties of the through-shaft construction, the first great advance was made in the direction of larger outputs at higher speeds. In very high-speed machines, the diameter of the shaft in the rotor core is necessarily small. As the overall diameter of the core is comparatively small, it follows that, after allowing for the slot depth, and the metal in the core necessary to withstand the high rotative stresses, there is left but little available space for the shaft. About 600 kv-a. capacity at 3600 rev. per min. was the limit with this construction.

The first great advance in this problem was made by the introduction of rotors without the through-shaft. By this means, the parts of the shaft adjacent to the rotor core proper, could be very much heavier than with the through-shaft type, and this combined, with the solid rotor core, gave great stiffness or rigidity compared with the former through-shaft type. This allowed much larger cores, with correspondingly increased outputs. The two-pole parallel slot type of rotor with bolted-on shaft construction, as described later, was apparently a leader in this respect, due to mechanical, rather than electrical, characteristics. When this type had proved to be a successful one, the possible capacities of two-pole, 3600-revolution, 60-cycle machines at once jumped from 600 to 1000 kv-a., and this was quickly followed by 1500, 2000 and 3000 kv-a. units at 3600 revolutions. Since then, the increase in capacity at this speed has been more gradual, but has been carried up to 5000 kv-a. at present, with possibilities of a 6250 kv-a. unit.

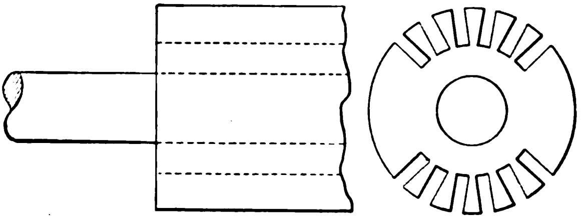

FIG. 1

The radial slot type of rotor, also described later, when constructed with its core and shaft in one piece, quickly followed the parallel-slot type in the above growth, and may eventually catch up with its only rival in the two-pole, 60-cycle field of construction.

About the same time that the through-shaft type was superseded in the two-pole, 60-cycle machine, a corresponding change was made in the two-pole, 25-cycle, and in four-pole rotors for both frequencies, so that, at the present time, practically no designs for the highest speed machines use the through-shaft type of construction. This latter, however, has been retained in some of the more moderate speed large capacity units.

On account of the high rotative and peripheral speeds, the general design of large capacity turbo-generators turns upon the type and construction of the rotor, rather than the stator. Various designs and types of rotors have been developed but, with rare exceptions, only two general types are now built in this country. These may be designated as the radial-slot and the parallel-slot types. Each has a number of advantages over its rival and each has given good results in practice.

RADIAL SLOT TYPE OF ROTOR

In the radial slot type, as usually constructed for high-speed machines, the core and shaft are forged in one piece in the smaller and more moderate sizes, but may be built up of a number of separate plates or disks bolted rigidly together in the larger sizes. In this type, the core is cylindrical in all cases, and in the outside surfaces are radial slots, usually arranged in groups, in which the exciting windings are placed. While all radial slot types of rotors bear a general resemblance to each other, yet there are marked differences in the method of forming the slots and teeth which constitute the outer surface. In some types the solid rotor core has radial slots milled or slotted in the main body of the core. In other cases the slots are formed outside the main core by inserted teeth, usually with overhanging tips, between which the exciting coils lie. These two general constructions are illustrated in Fig. 3. Examples of the inserted-tooth construction are found in the large moderate speed rotors of one American company, and in somewhat higher speed machines of a German company. However, with the advent of the high-speed, high capacity machines, the milled-in construction of the radial slots appears to be taking the lead, due to certain mechanical limitations in the inserted-tooth types.

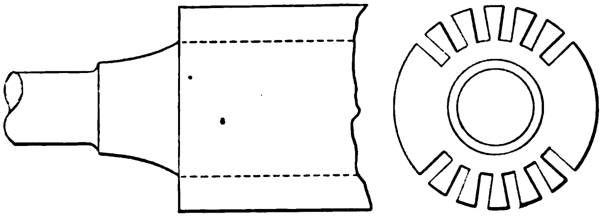

FIG. 2

On account of the radial slots and the usual concentric arrangement of the exciting coils, the field or exciting turns cannot be assembled and insulated before placing on the core, except in the inserted-tooth type of construction. With the milled-in-slot type, the field conductors, usually of flat strap, are dropped into the slot one at a time, with insulation between individual turns. For ease of winding, the ends are usually allowed to overhang the core, and require a very ample outside support in the very high speed machines. This is illustrated in Fig. 4. The completed coils are usually held in place by strong non-magnetic wedges in the tops of the slots. These wedges are usually carried by overhanging pole tips, in the inserted-tooth type, or by grooves in the sides of the slots in the milled-slot type. The design of the supports for the overhanging end windings has furnished one of the difficult problems in this type of construction. Examples of radial slot end windings, and of the rotor complete, are shown in Figs. 5 and 6.

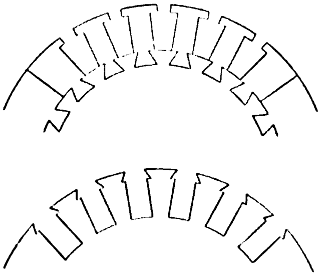

FIG. 3

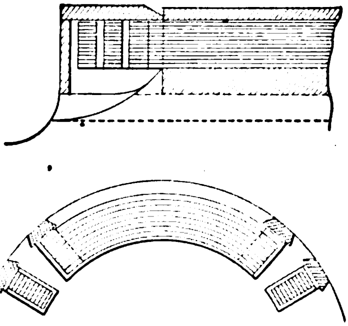

FIG. 4

This general construction of the radial slot type of rotor is obviously applicable to machines of any number of poles. With a two-pole machine there will be only two groups of coil slots and two groups of concentric coils, while with four poles or six poles there will be four or six groups respectively. It is evident that, with this construction, a cylindrical rotor is obtained, regardless of the number of poles. It is also evident that the problem of supporting the end windings becomes an increasingly difficult one, as the number of poles is decreased and the span of the end windings is correspondingly increased.

The support over the end windings usually consists of a heavy ring which, in very high-speed machines, must consist of material

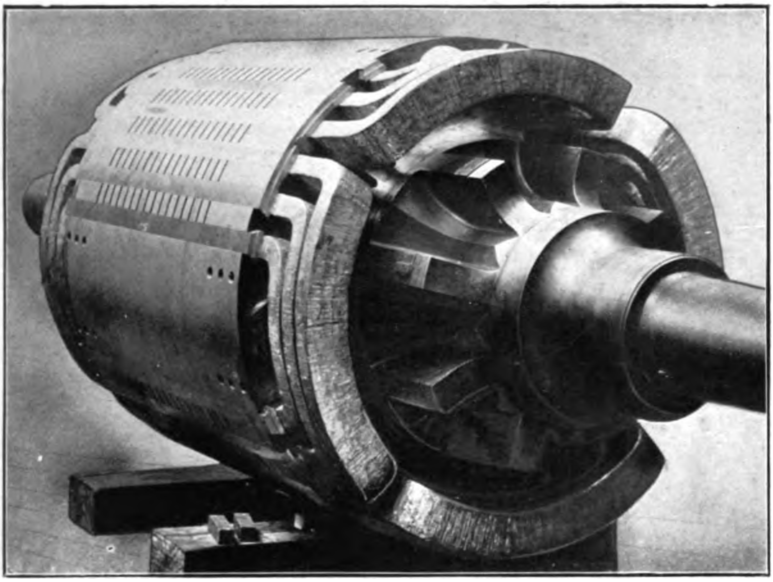

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FIG. 5

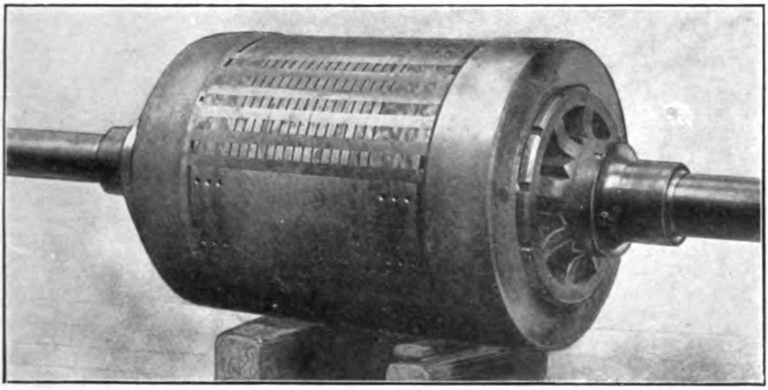

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FIG. 6

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having extra good physical characteristics, for this ring must not only be able to carry itself, but must also carry the weight of the underlying end windings which it supports. In the German inserted-tooth rotor, the end windings are supported by steel bands of many layers, instead of the solid steel ring. In some of the lower speed radial slot machines, such as one American type with inserted teeth, the end supports are of ring form usually made in a number of sections, which are bolted to an inner shelf by numerous bolts extending form the outer ring between the coils of the end windings to the inner shelf. While this construction is satisfactory for the more moderate peripheral speeds, yet with the much higher speeds in some of the later practise, this construction has been superseded by a solid ring type of support.

PARALLEL-SLOT TYPE OF ROTOR

In the parallel-slot type of rotor, the slots for the exciting coils, for any number of field poles, lie in planes parallel to one another and to the rotor axis. The arrangement is illustrated by Fig. 7. As usually constructed, the slots are cut across the ends of the poles, as well as in the sides, so that the exciting coils are embedded in metal throughout their length. The object of this general arrangement of parallel slots is to facilitate the winding of the exciting coils. The rotor can be placed upon a turn-table, or similar device, and rotated, to wind the coils in place under tension. Two or more coils can be wound at the same time, as is actually done in practice. As the coils can be wound under tension, and as the conductors usually consist of thin flat strap, which can be wound in very tightly, the resultant winding is a very substantial piece of work. The finished winding is supported by metal wedges over the coils.

It is obvious that, with this construction, no external support is required for the end windings, as the field core proper furnishes the necessary support. It is largely on account of this feature of well supported end windings that the parallel-slot type took a leading position during the growth of the larger two-pole, 60-cycle alternators. With the radial-slot type, the support of the end windings presented a more difficult problem in the large capacity, high-speed, two-pole machines, which, however, is being gradually solved.

In the two-pole, parallel-slot construction, in order to utilize the available winding space to advantage, it is necessary for the windings to cover the central portion of the core end where the shaft is usually attached, as shown before in Figs. 7 and 8. Therefore, with this construction, a separate " head " or driving flange must be bolted to the core at each end, this head carrying the shaft, as shown in Fig. 8. To avoid magnetic shunting of the field flux, this driving head must be made of non-magnetic material, usually of some high grade bronze, to which the shaft is attached in such a way as to keep the magnetic leakage as low as possible. This makes a good strong construction, but is necessarily rather expensive, due to the bronze driving heads. As these cost but little more for a long rotor than for a short one, the construction therefore tends toward relatively long, small diameter cores in order to lessen the relative dimensions of the bronze heads.

In two-pole, *single phase* machines of this construction, the copper cage damper for suppressing the armature pulsating reaction on the field, is comprised partly of these bronze heads, which form the " end rings " for the copper bars embedded in the slots in the rotor face.

In the four-pole, parallel-slot machine, no bolted-on driving heads are necessary, for the core proper and the shaft may be cast, or forged, in one piece, or in two or more pieces, which are bolted or " linked " together to form a solid core. The principal difference between the two-pole and the four-pole parallel slot constructions, is that the latter must have salient or projecting poles, in order to utilize the parallel construction for the slots, while the two-pole machine is preferably made cylindrical. Fig. 9 illustrates this feature.

It is evident that there is considerable available space lost by the openings between the projecting poles, while the sections of the poles themselves are cut down very materially by the slots for the exciting winding. The limitations therefore in such a rotor are in the magnetic section of the field poles and in the available copper space, and in these features the four-pole parallel slot rotor is inferior to the radial slot type. In the two-pole machine, however, the difference between the radial slot and the parallel slot is not nearly so pronounced, as is indicated in Fig. 10 where the two arrangements are shown on one core for comparison. It may be seen from this that, in the two-pole form, the two constructions approach each other, to a certain extent, some of the slots in the parallel construction being radial, while others depart but little from the radial. One disadvantage in the two-pole, parallel-slot type, however, lies in the smaller amount of

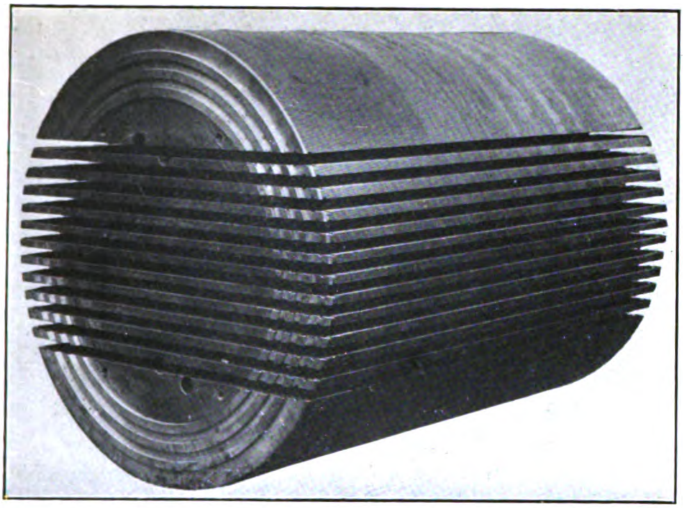

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FIG. 7

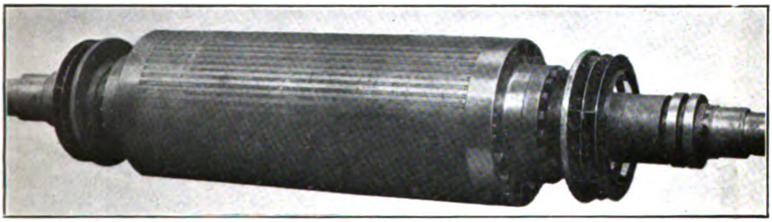

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FIG. 8

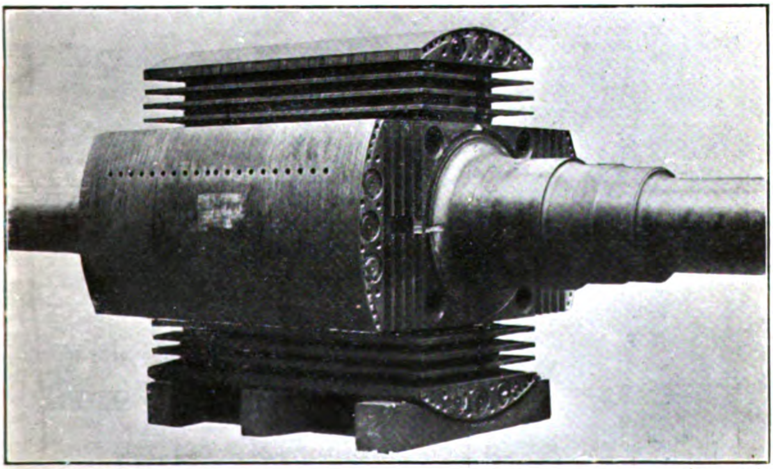

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FIG. 9

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copper space which is obtained, for the slot space must necessarily cover a less proportion of the total circumference than is permissible with the radial slot type. This winding space is limited by the physical requirements as regards bending and breaking strains in the overhanging tip *a* in Fig. 10. In the radial slot type, the slot space has no such limitation. Also, on account of the grouping of the field copper into a narrower zone in the parallel slot type, the heat conduction from the copper presents a more difficult problem than in the radial type.

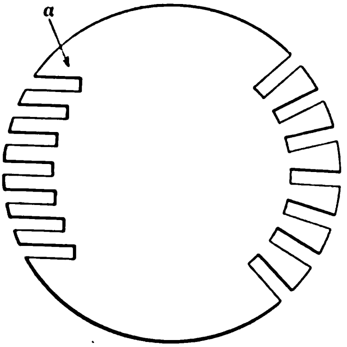

FIG. 10

At first glance, it would appear that the effective length of the field core in the parallel slot type is very considerably diminished by the slots across the ends of the core. However, this is only an apparent effect, for the true length of the core should be taken as that inside of the winding slots, and it should be considered that the additional length of the core at the pole face is in the nature of a coil support which takes the place of the separate support in the radial slot type. Therefore, if over-all lengths, including rotor coil supports, are compared in the two types, there is but little difference, as indicated by Fig. 11. However,

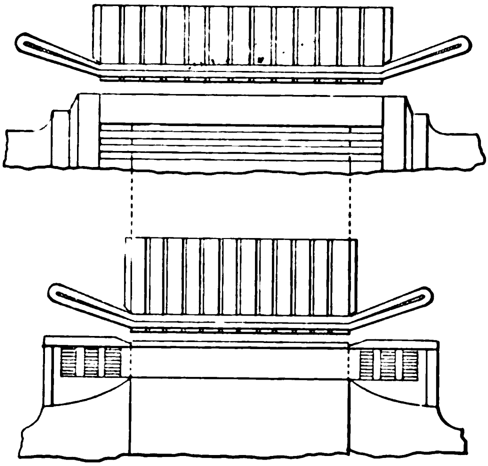

FIG. 11

if the armature core is made of the same width as the pole face, in both types of rotors, then in the parallel-slot type it will be materially greater than in the radial, for the over-hanging pole tips of the parallel-slot machine are also effective magnetically in furnishing flux to the armature. Therefore, as regards the stator, this tends toward a wider core in the axial direction, and a shallower depth of iron back of the armature slots, as indicated in Fig. 12. Also, on account of the relatively larger polar surface, in the parallel slot type of rotor, the magnetic flux density in the air gap is usually relatively smaller than in the radial slot type, which conduces towards a larger depth of air gap. Also, on account of the larger polar surface, the available space for armature slots and teeth is correspondingly increased. Therefore, this type of construction is better adapted for the straight air gap method of ventilation, as will be described later. The greater section available for slots and teeth at the stator pole face permits a large number of ventilating ducts. The relatively large depth of gap allows a large amount of air to be fed through the air gap to the ducts. Therefore, the " radial " type of stator core ventilation has been used very largely with this type of rotor construction. In the parallel-slot type of rotor, it is obvious that, due to the large polar surface compared with the minimum section of the field core, a limit in design is found in the magnetic saturation in the field core itself.

In the four-pole parallel-slot rotor, the field section is more limited than in the two-pole machine, due to the fact that considerable magnetic space is lost by the notches between the projecting poles. However, in this type of construction, the air gap method of ventilation is relatively easy, due to the fact that these interpolar spaces furnish easy access of the ventilating air to the stator ventilating ducts. In consequence, the problem of ventilation is usually not a serious one in this type of rotor. Due to the polar projections, however, the tendency to noise is obviously greater than in either the radial-slot type or the two-pole parallel type, which are always cylindrical.

Nothing has yet been said as to the peripheral speeds obtained in some of the actual designs of the higher speed generators. These, in themselves, indicate some of the limitations which now confront the designer.

In the 5000 kv-a., two-pole, 3600-rev. per min., 60-cycle generator already referred to, which is of the parallel-slot rotor construction, the rotor diameter is 26 in. (66 cm.) This gives a

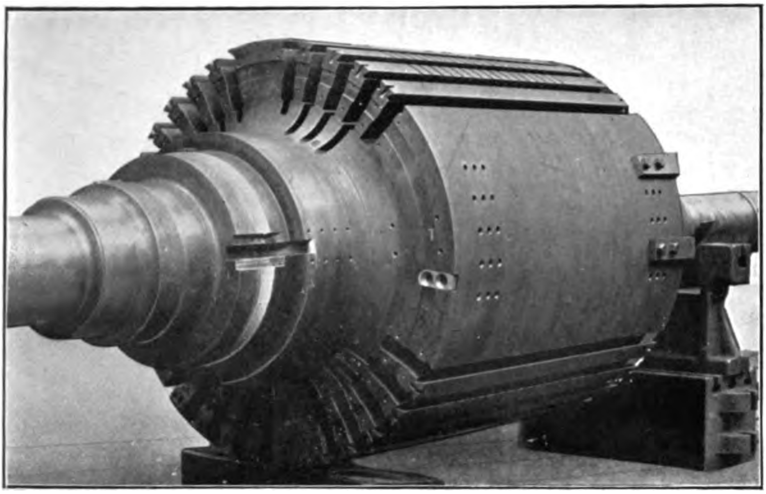

FIG 12

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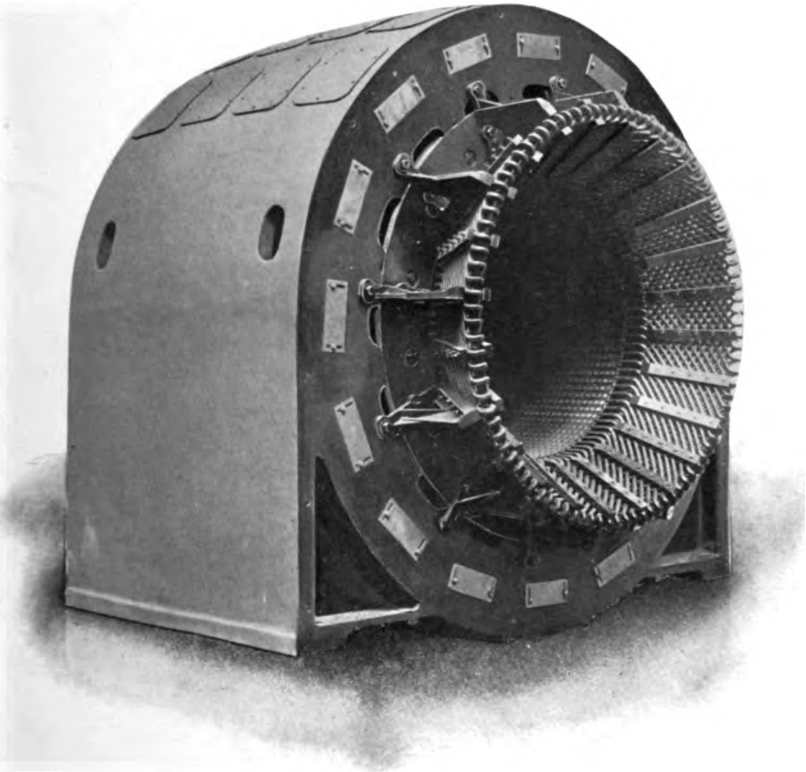

FIG. 21

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peripheral speed of 408 ft. (124.3 m.) per second, or approximately 24,500 ft. (7468 m.) per minute. The core is designed for a very considerable margin of safety, and is actually tested at overspeeds which give practically 30,000 ft. (9144 m.) peripheral speed at the surface of the core.

In certain 19,000 kv-a., 62½-cycle, four-pole, 1875-rev. per min. machines now being built, which are of the radial-slot rotor construction, the rotor diameter is 49 in. (124.4 cm.) This gives a peripheral speed of 24,000 ft. (7315 m.) per minute. This compares with a speed of 21,600 ft. (6583 m.) in a 21,000 kv-a. two-pole, 1500-rev. per min., 25-cycle, radial-slot machine also being built, the rotor core of which is shown in Fig. 12. Obviously the mechanical limitations are being more closely approached in the 60-cycle machines, up to the present capacities.

If a comparison is made between the above 5000 and 19,000 kv-a. rotors, with their parallel and radial type constructions, it is found that their limitations lie in quite different features. In the radial-slot type, the core stresses are much lower than in the other, but the supporting end ring is an important problem, requiring for its solution, a very high grade steel for the material of the ring. In the parallel-slot rotor, the maximum stresses are in the core itself, principally in the parts which overhang the slots at the sides and ends of the core. In the radial slot core, there are no such overhanging masses. In both constructions, the core material is purposely made of relatively soft steel, having a high percentage elongation, the object being to obtain a material which can yield sufficiently to transfer the strains from local higher points, to adjacent lower parts, and thus equalize them, to a great extent.

The smaller diameter rotor cores are made of steel forgings, in one piece. The larger cores are made up of thick steel plates assembled and bolted together to form a solid mass comprising the core and shaft extensions. By this disk construction, commercial material is used which is of uniform quality clear to the center of the disks. The fiber of the material is in a direction best suited to the directions of stress. With corresponding size disks made in one piece, the outside, to a certain depth, can be given fair physical characteristics, but the center is liable to be glass-hard, as found by experience. However, this may not be a prohibitive condition in machines of more moderate peripheral speeds. Herein lies one great difference between American and European limitations. In American practice, 60-cycles, calling for 3600 and 1800-rev. per min. machines, is the standard frequency, while in Europe, 50-cycles is standard, giving 3000 and 1500-rev. per min. machines. These lower speeds make an enormous difference in the possibilities of design and construction.

PRESENT LIMITATIONS IN DESIGN

On account of the very great capacities, at high speeds, now being obtained in turbo-generator practice, a number of problems are being encountered, the solutions of which are producing more or less radical changes, both in design and in practise. Some of the limitations now encountered are in the relatively high temperatures in certain parts, high losses in a relatively small space, the difficulty of ventilation, due to the requirement of enormous volumes of cooling air through limited openings or passages, the type of insulation, fire risks, regulation and short circuit conditions, etc.

A number of these limiting conditions, such as the temperature, ventilation, losses, and insulation, are so closely related to each other, that it is difficult to describe any one of them in detail, without including the others to a considerable extent.

THE PROBLEM OF VENTILATION

In the general problem of ventilation, four conditions must be considered, namely, the total loss, or heat, developed, the surface exposed for dissipating this heat to the air, the quantity of air required to carry away the heat, and the temperature of the cooling air.

In the conduction of heat from the surface of a body into the air, the quantity of heat per unit area which can be dissipated depends upon the difference in temperature maintained between the surface of the body and the body of air to which the heat is conducted. The heat dissipated raises the temperature of the adjacent air a certain amount, and thus tends to reduce the temperature difference, unless the air is renewed with sufficient rapidity. On the other hand, if the quantity of air is so great, in proportion to the heat dissipated, that there is but little rise in the air temperature, then any increased amount of air over the surface will represent practically no gain in ventilation. In other words, when the amount of air passed over a surface is sufficient to take up the heat dissipated from the surface without an undue rise, then a further quantity of air is wasteful, and it may even be considered as indirectly harmful, in those cases where the total quantity of air is limited. This has a direct bearing on the size of ventilating ducts or passages in a machine. If the air path through a duct is relatively long, then a considerable width of duct may be required in order to get the necessary quantity of air through it. On the other hand, if the air path is very short, then a very narrow duct may be most effective, for a wider duct may allow more air to pass through than can be utilized in taking up the heat.

No matter how thoroughly the ventilating air is distributed through the heat-generating body, or however effective the heat-dissipating surfaces may be, the total air supplied must be ample in quantity, or its temperature will be raised an undue amount. As the surfaces to be cooled must always have a higher temperature than the cooling air, any considerable rise in the latter will have a direct influence on the ultimate temperature which may be attained by the body to be cooled. Conversely, if an ample quantity of cooling air is supplied, but the heat-dissipating surfaces are insufficient, the ultimate temperature of the body will also be affected.

In large capacity, high-speed turbo-generators, the problem of ventilation is one of the most difficult ones encountered. The trouble lies principally in the large total loss expended in a very limited space. The difficulties of the problem may be illustrated by the following example:

Assume, in a 1500-rev. per min., 25-cycle, 15,000-kv-a. machine, a total efficiency of 96.5 per cent, including air friction loss inside of the machine. This means a total loss in the machine of 565 kw., which is not excessive for this capacity, but is very large for the limited space in which it is developed. A very large volume of cooling air is required for carrying away the heat due to this loss. A simple approximate rule for determining the quantity of air required is that an expenditure of one kw. in one minute will raise the temperature of 100 cu. ft. (2.8 cu. m.) of air 18 deg. cent. Therefore, 565 kw. loss would require a supply of ventilating air of approximately 50,000 cu. ft. (1416 cu. m.) per minute for a rise of the out-going air of 20 deg. above that of the incoming air. Assuming a velocity of 3000 ft. (914 m.) per minute, this would mean, with a cylindrical ventilating channel, a diameter of 56 in. (142.2 cm.), which is greater than the rotor diameter itself. However, as the cooling air ordinarily would be supplied to both sides of the machine, the ventilating passage need only be half the above section for each side.

Obviously, such passages are prohibitively large, and much greater air velocities through the machine proper are necessary. Velocities as high as 5000 to 6000 ft. (1524 to 1828 m.) per minute are common, while, in some cases, more than 10,000 ft. (3048 m.) per minute has been required in certain constricted sections of the air path inside the machines. Therefore, no matter how the problem is considered, it may be seen that the above condition of the enormous volume of air required, makes the problem of ventilation a difficult one.

There are several methods of ventilating large turbo generators, depending upon the system of applying the air. There is, first, the radial system, in which practically all the cooling air passes out radially through ventilating ducts in the stator core. This radial system of ventilating can be subdivided into two alternative methods, depending upon whether the air is partly or wholly supplied through passages in the rotor, or through the air gap alone. These two methods are illustrated in Fig. 13. The straight air gap arrangement may require a relatively large air gap, combined with very high velocity of the air along the gap, while the other method permits a considerably shorter gap. The straight air gap method of ventilation is used, to a considerable extent, in all 60-cycle machines of two-pole construction, while it is practically the only one that has been used with the parallel-slot type of machine with either two or four poles. In this parallel-slot type of rotor, however, the air gap can be relatively larger than the radial-slot type of rotor, as explained before, which compensates, to some extent, for the necessity of depending upon this method entirely. In the four-pole parallel-slot rotors, the interpolar spaces are also effective. Moreover, with parallel-slot rotors in general, the openings from the air gap into the stator ventilating ducts can usually be somewhat larger in total section than with the radial type of rotor, as also described before. However, the relatively greater axial length of the core of the parallel slot type of rotor increases the length of the constricted air passages along the air gap in the two-pole machines, which is a material disadvantage.

The straight air gap type of ventilation has proven astonishingly effective in cooling the rotor in both the radial and parallel-slot types of rotors, and with either type there is usually no great difficulty in forcing through enough air to cool the rotor core in a fairly effective manner. It must be considered, however, that the total rotor loss in large turbo-generators is possibly only 10 per cent of the total loss which must be taken care of, and a relatively small proportion of the total ventilating air may suffice to cool it. According to actual measurements, corroborated by general experience, the cylindrical surface of the rotor core can give off four or five watts per square inch (6.45 sq. cm.) to the cooling air, with a temperature rise of the rotor surface of about 35 to 40 deg. cent. above the cooling air. To those who have had experience with dissipating heat from electric apparatus, this result will appear to be extremely good.

The real difficulty with the air gap method of ventilation, is not so much in getting enough air through for cooling the rotor itself, but it is in the much larger quantity required for the stator. For instance, a one-inch (2.54 cm.) depth of gap (from iron to iron) with a 50-in (127-cm.) diameter of rotor, means a total section of air path into the gap (counting both ends of rotor) of 314 sq. in. or 2.18 sq. ft. (0.19 sq. m.). At a velocity of 10,000 ft. (3048 m.) per minute, this allows a flow of only 21,800 cu. ft. (617 cu. m.) per minute, which will not take care of a large machine, from the present standpoint of possible capacities with the above diameter of rotor. By additional openings in the rotor core, this might be increased to 30,000 cu. ft. (849 cu. m.) per minute, but even this is still

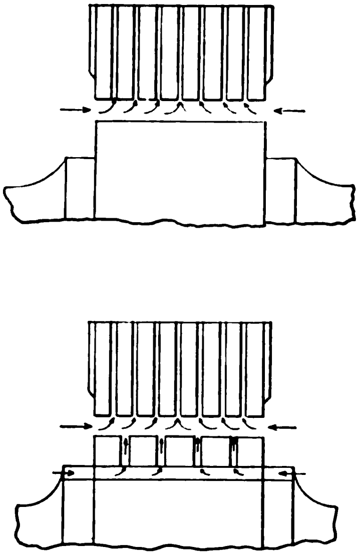

Fig. 13

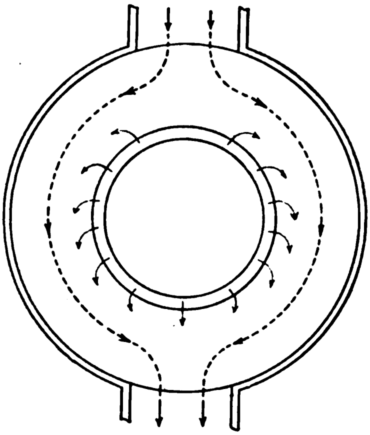

Fig. 14

much less than a machine, with a 50-in. (127-cm.) diameter of rotor, would require if built for capacities otherwise possible. Therefore, on account of this limitation in the amount of cooling air, other means of ventilation have received much consideration. Two other general systems of ventilation, in addition to the gap method, have been used, namely, the circumferential method, and the axial. The former has been developed and applied more extensively in the past, but the latter contains possibilities which are bringing it rapidly to the front.

In the circumferential method of ventilation, air is supplied to one or more points on the outside circumference of the stator, and is forced circumferentially around through the air ducts to suitable outlets, also on the outside surface. Air gap ventilation is usually combined with this circumferential method, partly to cool the rotor. The general arrangement is indicated diagrammatically in Fig. 14, in its simplest form, namely, with one inlet and one outlet diametrically opposite. A serious objection to this method of ventilation is found in the limited section of the ventilating path. Assuming, for example, a depth of stator core of 20 in. (50.8 cm.) outside the armature slots and a total of 40 $\frac{3}{8}$-in. (9.5 mm.) ventilating ducts, or a total effective duct space of 15 in. (37.1 cm.) width then this gives a total section of ventilating path of $20 \times 15 \times 2 = 600$ sq. in., or 4.16 sq. ft. (0.386 sq. m.). On account of the relatively great length of the ventilating path, air velocities of more than 6000 to 7000 ft. (1828 to 2133 m.) are not desirable or economical, but even with 10,000 ft. (3048 m.) velocity, the total quantity of air would be only 41,600 cu. ft. (1166 cu. m.) per minute. Furthermore, this method is handicapped in machines with very high-speed rotors, by interference between the radial and the circumferential systems of ventilation, so that the full benefit of either is not obtained. Below a certain rotor velocity, apparently the circumferential action can predominate, and the method is fairly effective up to the permissible air capacity of the stator ducts; but at very high speeds the radial ventilation may very seriously interfere with the other, so much so, that the radial ventilation alone, even with its very restricted gap section, may give as good results as the two methods acting together.

To avoid this interference, various methods have been devised, such as closing part, or all, of the radial ventilating ducts at the air gap to keep the radial effect from interfering with the other. One arrangement which has been used in Europe to a considerable extent is indicated in Fig. 15. In this, the alternate radial air ducts are closed at the outside surface, while all are closed at the air gap. The air enters by the ducts open at the back of the machine, flows both circumferentially and toward the gap, and crosses over to the immediate ducts by axial openings back of the armature teeth, and then along these ducts to the outlet. This scheme is effective in principle, but is uneconomical in the sense that less than the total section of stator ducts is useful, as regards the quantity of air which can be carried. There is usually one large central duct to allow an outlet for the rotor ventilating air. This particular arrangement of the stator also uses axial ventilation in crossing over from one set of ducts to the other, which is an effective arrangement.

A modification of the simple circumferential method of ventilation is to admit air to the back of the stator at two opposite sides of the machine, and deliver it at two outlets at intermediate points on the surface, as shown diagrammatically in Fig. 16. By this means, the cross section of the ventilating path is doubled and the length is halved. Also, the interference of the radial ventilation with the circumferential will be less harmful. A serious disadvantage in the circumferential ventilation in general is that the ventilating path is relatively long, especially where there is but one inlet and outlet, and therefore the cooling air at the outlet of the channel may be considerably hotter than at the inlet, with consequent less effective cooling action. This means points of local higher temperature in the core, due to the method of ventilation. In the radial type of ventilation, the coolest air is applied near the seat of the highest losses, namely, at the armature teeth, and immediately back of

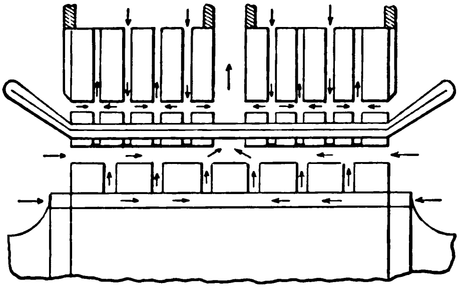

Fig. 15

them, and the air, as it becomes heated, passes over the outer part of the iron which has a diminished loss, and therefore normally less heat to dissipate. Therefore, the effect of the increased temperature of the cooling medium is offset by the lower loss, and consequent less necessity for ventilation, in the part where the air is hottest. The radial system of cooling is therefore theoretically the most effective, but practically, the difficulty is in applying it, due to the limited air passages available.

Both the circumferential and the radial methods of cooling are subject to one serious defect, namely, most of the generated heat in the stator iron must be conducted across the laminations to the air ducts. The rate of conduction across the laminations is only from 1 per cent to 10 per cent as great as along the laminations themselves, according to various authorities. Therefore, if the heat could all be conducted along the laminations to the ventilating surfaces, apparently much more effective heat dissipation could be obtained, provided sufficient surface is exposed to the air, and an ample quantity of air supplied. This has led to the development of the axial system of ventilation, as distinguished from the radial and circumferential. In this method, a large number of axial holes are provided in the stator core which may extend uninterruptedly from one side of the core to the other, or they may extend from each side to one or more large central radial channels which form the outlet. The usual numerous radial ducts are omitted, or may be con-

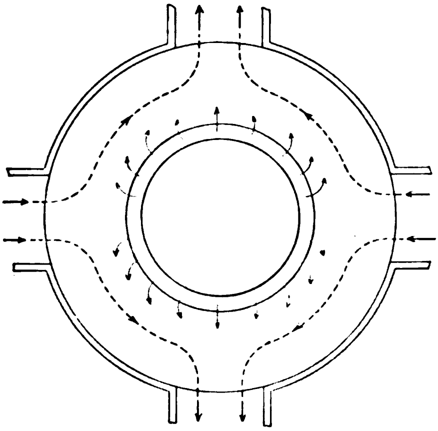

FIG. 16

sidered as combined in one central channel. This general arrangement is illustrated in Fig. 17. The rotor cooling is accomplished by air along the air gap, and through the rotor core to the large central duct. In this method of ventilation therefore, there is a combination of two types, namely, the axial and the air gap, but there is not the interference between the two, that is sometimes found where the circumferential method is used.

From the preceding, it may be seen that the problem of putting a sufficient quantity of air through the machine is an extremely difficult one. In addition, in very large machines, the problem of supplying the required quantity of air from a suitable blower forms another serious problem. In smaller capacities, and in slower speed machines, it has been the usual practise to attach blowing fans to the rotor shaft or core, as part of the outfit. There is no particular difficulty in this arrangement, except, possibly, in the high-speed construction of the fans required for 60-cycle, two-pole machines. Such fans can supply an amount of air which is limited by the diameter and other dimensions of the fan itself.

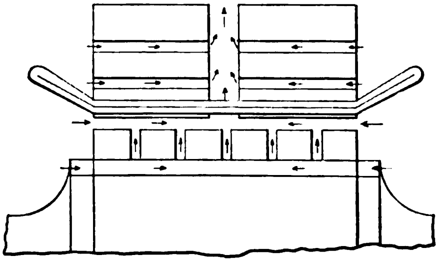

FIG. 17

Assume, for example, that by lengthening the rotor core, or by other modifications in the construction, the capacity of the machine can be doubled, and therefore double the quantity of air is required for cooling. If the limit of the fan design or operation was reached before, then obviously some radical change is required with the new capacity of the machine. This condition apparently has been reached in some of the later practise in large, high-speed turbo-alternators. One obvious solution of this difficulty lies in the use of separate slower speed, large diameter, fans or blowers. This may appear to be a step backward, but when the above conditions and limitations are taken into account, it is not so. The "tail" must not be allowed to "wag the dog;" the blower, which is an adjunct, must not be allowed to dominate the construction of the machine itself. Moreover, there are a number of meritorious features in the use of a separate blower. In the first place, it can be made somewhat more efficient than the high-speed, rotor-driven fans. Again, with a suitable means to drive, variable speeds, and therefore different air pressures, can be obtained. This feature may prove to be very desirable or advantageous under peak, or overload, or emergency conditions.

One further condition keeps cropping out in the general problem of ventilation, namely, that of filtering or washing, or otherwise cleaning the ventilating air. With 50,000 to 75,000 cu. ft. (1415 to 2122 cu. m.) of air per minute passing through a large machine, obviously in a year's time, an enormous quantity of foreign matter is carried through the machine with the ventilating air. A deposit of a very small per cent of this in the machine will probably be disastrous. In fact, however, the high velocity of the air through the machine serves to keep the air passages clear if no oil or moisture is allowed to enter. That a large amount of foreign matter does go through the machine is very soon shown in case a little oil is allowed to get into the ventilating passages. This oil catches the dirt and in a short time the ventilating passages may be very materially obstructed.

On account of the deposit of dust, etc. in the ventilating passages, it is necessary to clean certain types of machines at more or less frequent intervals, and it is advisable to clean all types occasionally. With some systems of ventilation, where such cleaning is difficult, or almost impossible, such as that shown in Fig. 16, provision must be made for cleaning the air before it enters the machine. With the particular construction shown in Fig. 16, air filters are almost always supplied. In the American types of construction, however, such filters have not yet been used, except in a more or less experimental manner, due probably to the greater accessibility of these machines as regards cleaning. But such filtering processes possess considerable merit in general. One modification which is being agitated at present is that of washing, instead of filtering, the air. This serves the double purpose of cleaning and cooling the air, and in very hot weather, when the available capacity of the machine is at its minimum, this cooling effect may mean a reduction of 6 to 10 deg. in the temperature of the machine.

THE TEMPERATURE PROBLEM

In the general problem of temperatures in electrical apparatus, it is not the rises, but rather the ultimate or limiting temperatures which are of first importance. Furthermore, the real limitation in ultimate temperature does not lie in the copper and iron, but in insulating materials used; and only insofar as the temperatures of the former affect the latter do they concern the general problem. However, as insulating materials in themselves are not usually sources of heat, but as they receive most of their heat from adjacent media, such as iron or copper which may be generating loss, the real temperature problem, as regards insulation, resolves itself into the consideration of that of the adjacent materials. Therefore, it is one which, for its full analysis, requires a knowledge of the sources and amounts of heat generated, and its conduction and distribution to other parts.

Broadly speaking, there is always a flow of heat from points of higher to those of lower heat potential and the amount of flow is also a function of the quantity of heat generated, the section and length of the paths through which it can flow, and the specific heat resistance of the various materials which conduct the heat. In an electric generator, for example, heat is generated in large quantities in the armature teeth and in the armature core. It is also generated in the armature coils when the machine is carrying load. Part of the armature copper is buried in the armature slots where it is almost surrounded by iron, which, in itself, develops a loss, while another part, such as the end windings, may be surrounded by, and thoroughly exposed to, the ventilating or cooling air. In such end portions, the flow of heat will usually be from the inside copper, directly through the insulation to the cooling air. The amount of heat which will flow from the copper through the insulation, depends upon the temperature differences between the copper and the outside surface of the insulation, upon the cross section of the path of flow, upon the thickness and " make-up " of the material, and upon the heat-conducting properties of the insulation itself. There is also a considerable temperature gradient from the outside surface to the air. If the surrounding air is not renewed with sufficient rapidity, the flow of heat from the insulation to the air may raise the temperature of the adjacent air, so that the total temperature drop is decreased, and the amount of heat dissipated is correspondingly reduced.

In the armature core, the problem is much more complex.

In the copper buried in the armature slots, there are usually three paths along which the heat can flow: First, it may flow from the copper directly through the insulation to the iron, provided the adjacent iron temperature is lower than that of the copper. Second, it may flow lengthwise of the copper to the end windings to be dissipated directly into the air from that portion of the winding, as described above. Third, in the case of open-slot machines, one edge of the coil may be exposed to the air in the air gap, and there may thus be a direct conduction of the heat through the insulation to the air in the air gap. This latter case, however, only holds for the upper coil, or that next to the gap, in the case of two coils per slot, which is the most common construction. In the bottom coil, the only means of conduction in the buried portion of the coil, are to the adjacent iron or lengthwise to the end windings, or to the adjacent upper coil, which, however, would normally have at least as high temperature as the lower coil. Therefore, the two effective paths should be considered as through to the iron and thence to the air, and lengthwise of the copper to the end windings and to the air. It is the relation of the various factors of these two paths that control the actual temperatures.

It has usually been considered that, in the buried copper, the greater portion of the heat is conducted directly into the surrounding iron. This, however, is only partially true, depending upon many features in the construction and type of apparatus, The heat conductivity of copper is, roughly, about six times that of laminated iron lengthwise of the sheet, which is possibly ten to twenty times as great across the laminations. In an armature which is comparatively narrow and which has very open, well ventilated end windings, a relatively small difference in temperature between the copper at the center of the core and that in the end windings, may cause a relatively large flow of heat from the buried copper to the end copper. Therefore, in certain designs, a great part of the armature copper heat may be dissipated through the end windings, and not through the armature core, especially in those cases where the armature core in itself has a considerable temperature rise. There even might be no conduction of heat from the copper to the iron, or there may be conduction from the iron to the copper; for it the copper is at the same temperature as the iron at the center of the core, for instance, then at each side of the center, or as the edges of the core are approached, the copper temperatures will be relatively lower than at the center, and therefore lower than the adjacent iron, on the assumption that the iron temperatures would be practically constant over the full width of the core. The conditions would therefore be as represented in Fig. 18. The solid line *a* in this figure represents the iron temperature at uniformly 40 deg. cent. rise, and the dotted line *b* represents the copper temperatures from the center of the core to the edges. The temperatures at the center being assumed the same for copper and iron, obviously there will be a flow for heat from the iron to the copper near the edges of the core. The effect of this additional heat carried out by the copper would be such as to tend to increase the temperature of the copper at the center of the core by " banking up " the copper heat.

Again, if the temperature of the copper at the center is materially higher than that of the surrounding core, the conditions may be as represented in Fig. 19. In this case, assuming the core at constant temperature, there will be heat flow from the copper to the iron at the center of the core, and from the iron to the copper at the edges.

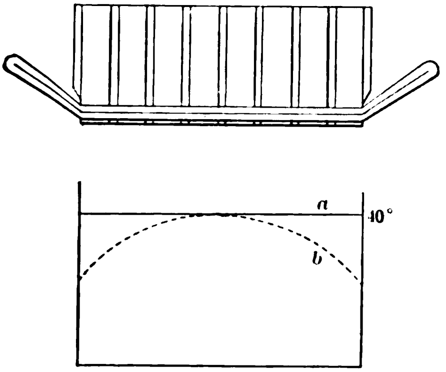

FIG. 18

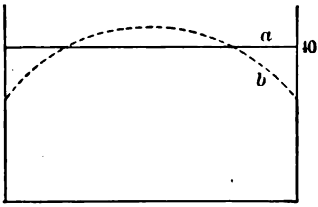

FIG. 19

This study of the problem leads to certain very curious conditions which are sometimes found in large machines. At no-load, for instance, with practically no copper loss present, and with high iron loss, there may be a very considerable flow of heat from the armature teeth through the insulation into the copper, and thence to the end windings and to the air. In this way the temperature of the armature teeth at no-load, and with normal voltage generated, may be considerably reduced by conduction of the iron heat into the copper, while the copper itself may show a very considerable temperature rise. When load is placed upon such a machine, sufficient to raise the temperature of the copper up to that of the iron in the armature teeth, the latter is actually increased in temperature, due to the prevention of the heat conduction into the copper. In this way, therefore, the copper may apparently heat the iron, although there is no direct flow of heat from the copper to the iron, but the reverse flow is prevented.

In high-voltage windings requiring thick insulation, the temperature drop from the copper to the outside may be relatively large; that is, with a given difference of temperature between the copper and the surrounding air, a relatively small amount of heat may be conducted through the insulation. Experience shows that the amount which can be conducted is a function of the quality of the material, the way it is built up, its thickness, and also the pressure upon it. It is almost impossible, in a machine in service, to calculate exactly the flow of heat, even if all the temperature conditions are known, for the insulating material itselt is one of the variables in the problem. The ability of the insulation to conduct heat will change with operating conditions, to some extent, as, for instance, it may tend to expand somewhat under heat, and thus change its heat conducting qualities.

In the armature iron, the problem of heat conduction is just as complicated as in the armature conductor. The principal sources of heat lie in the armature teeth and in the armature core back of the teeth. As a rule, the loss in the portion of the core immediately back of the teeth is relatively greater than at a greater depth, for the magnetic fluxes which cause the temperature rise, generally crowd close to the teeth, so that the density is higher at such parts.

The heat from the armature teeth can be dissipated along several paths. It can flow lengthwise of the laminations to the end of the tooth and into the air gap, where the ventilation is usually fairly good, but the tooth surface exposed is relatively small. In the second place, it can flow back along the laminations to the armature core where it can spread out through a path of much greater cross section and be conducted partly to the back part of the laminations, and partly transversely to the ventilating ducts. A third path from the armature teeth is across the laminations of the teeth, to the neighboring ventilating ducts. This latter path, however, must necessarily be relatively poor in conductivity per unit section of path, compared with the others, but offsetting this, it is frequently of much greater cross section and of relatively small length. In passing from plate to plate, the heat must pass through the insulating varnish, or other material used, which is of relatively high heat resistance compared with the iron itself. Nevertheless, in machines with radial ventilation, a very considerable portion of the heat due to the tooth loss is carried transversely through the plates to the air in the ventilating ducts, simply because that is the path of lowest total heat resistance, everything considered. In many cases, the temperature in the core back of the teeth may be as high as that of the teeth themselves, so that the only flow possible is across the laminations to the air ducts, or lengthwise to the tip of the teeth in the air gap. Therefore, the question whether the armature teeth may be hotter than the armature core, or whether the flow of heat is from the teeth to the core, or from the core to the teeth, is a very involved one; and yet upon this question depends, to a great extent, the temperature rise in the buried armature copper. If the armature core is normally hotter than the teeth, and a considerable amount of heat in the teeth is carried away by the buried copper at no load, then it may happen that when carrying heavy load, the heat in the teeth will rise very considerably above the no-load condition, and it may actually so " bank-up " that there is still more or less flow from the iron to the copper, even with load. With such a condition, therefore, the outside of the insulation may reach a higher temperature than the inside, while in those cases where the temperature of the copper rises above that of the iron of the armature teeth, the inside of the insulation will be hotter. Therefore, the temperature to which the insulation is liable to be subjected appears to be largely a problem for the designer to determine from his calculations, based upon accumulated data and experience. This is especially the case with very wide armature cores and large, heavily insulated armature coils, such as found in large capacity, high speed turbo generators. In such machines, experience has shown that various temperature conditions may be found, depending upon the location and relative values of the losses in the different parts and the means for conducting away the heat. Tests have shown that, in some cases, the armature iron at the center of the core is considerably warmer than the armature copper, while in other cases the opposite is found to be true.

In such apparatus, the temperatures actually obtained are liable to be materially higher than the usual methods of measurement will indicate. These temperatures are inherent to the conditions of design and cannot be avoided economically, in certain types of apparatus, such as turbo-generators. In such machines, the limitations in speed, strength of material, etc. force the designer to certain proportions which preclude larger dimensions, or lower inductions in the iron, or lower densities in the copper, or increased ventilation. In such apparatus therefore, the development apparently lies in the direction of insulations which will stand the higher temperatures which may be obtained.

These conditions of higher temperatures in some parts of the machine, than indicated by the usual tests, have been recognized for years by designers and manufacturers of large electric machinery. A rough indication of these temperatures can be obtained by exploring coils or thermo-couples suitably located. However, it is evident that such coils, if located next to the copper, will not give the correct temperature measurement if the flow of heat is from the iron to the copper, while a coil next to the iron will not give the correct result with the flow from the copper to the iron. Experience has shown that the temperatures, in corresponding positions around the core, may not be uniform, due to local conditions. In consequence, it is not practicable to actually determine the true temperatures of all parts of the insulation on commercial machines, except by measurements of a laboratory nature, which would involve such a number of separate readings as to be commercially prohibitive.

On account of the higher temperatures which may be found in such apparatus, and the difficulty of making exact measurements, except by laboratory methods, manufacturers very generally have adopted the use of mica as an insulating material on the buried part of the coils. Experience has shown that such material, when properly applied, can safely stand temperatures of at least 125 deg. cent. How much more has not yet been determined.

Of such machines it may be said that the manufacturer, with his guarantee of 40 deg. cent. by thermometer, actually builds for possible temperatures of 70 to 90 deg. cent. in some parts of the machine, for he expects to find fairly high temperatures in some cases with exploring devices. The usual guarantee of 40 deg. cent. therefore should be considered as only a relative indication of a safe temperature in such apparatus.

If, for instance, the exploring coils should show 70 deg. cent. maximum rise under running conditions, and the permissible ultimate temperature of fibrous or tape insulation is assumed as 90 deg. cent. for continuous operation, then obviously, with air at 40 deg. cent. the insulation would be considered as insufficient from point of durability, except for intermittent service, such as overloads, and such limited conditions. Plainly, the insulation, for such temperatures, should be of mica, or equivalent material, for which 125 deg. cent. has been found to be safe.

Furthermore, it may be stated that with such mica insulation, a turbo generator which shows 75 deg. cent. rise by exploring coils, or thermo-couples, has, in fact, more margin of safety than the ordinary varnished-tape-insulated low-voltage machines of any type, which show 40 deg. cent. rise by thermometer or 50 deg. cent. rise by resistance.

The foregoing aims to bring out clearly that the temperature problem is a most complex one, in all electrical apparatus, and especially so in turbo-generators. It indicates that no simple temperature test can show all the facts, and that all commercial methods must be considered as approximations. It also shows the absurdity of classifying a piece of apparatus as *good* or *bad*, respectively, according to whether it tests possibly one or two degrees below or above a specified thermometer guarantee. Also, following out the above principles on heat flow, various fallacies in temperature measurements might be noted. For example, it is usually assumed that, after shutdown, if a gradually rising temperature is shown, this is a more accurate indication of the true temperature. But this may be entirely wrong as regards windings. If, for instance, the core back of the armature slots is materially hotter than the armature teeth while carrying load, then, upon shut-down, with the air circulation stopped, the teeth will rise to approximately the same temperature as the core back of the teeth, and there may be a flow of heat into the coils, which condition may not have existed while carrying load. A thermo couple on the coil or in the teeth would thus indicate a false temperature rise after shut-down. This is cited simply as one of many instances, to show the possibilities of entirely wrong conclusions which may be reached in the problem of temperature.

THE INSULATION PROBLEM

The one fundamental condition which must be considered in the insulation problem, is the durability of the material itself, and this must be viewed from two standpoints,—the mechanical, and the electrical. From the mechanical standpoint, the material may have its insulating qualities impaired by the action of mechanical forces which tend to crack, or crush, or disrupt the material itself, or it may be affected by being permeated by foreign materials or substances, or it may be injured by such overheating as will partially or wholly carbonize it, or render it brittle or otherwise unsuitable for the desired purpose.

From the electrical standpoint, it may be weakened by deterioration of the quality of the insulating material itself or some of its component parts, which may be due to heating, or oxidation, or many other causes.

The effect of mechanical injury, such as cracking crushing or overheating, on the insulating qualities, will depend upon many conditions. In some cases, with relatively low voltage, any effective mechanical separation of the parts is sufficient for electrical purposes. For higher voltages, continuity of the separating insulating medium is necessary.

Experience has shown that, for moderate voltages, temperatures which may injure, or even ruin, the insulating material, from a mechanical standpoint, may not seriously affect its insulating qualities. Many insulating materials of a cellulose nature will still retain good insulating qualities if maintained at temperatures as high as 150 deg. cent. for such long periods that the material itself semi-carbonizes. Under such high temperature conditions, however, it becomes structurally bad,—that is, it may become so brittle that it tends to crumble, or powder, or flake off, and thus its value as an insulation is impaired by displacement of the material itself. In low voltages, therefore, it is not a deterioration in the insulating qualities, but rather a mechanical breakdown of the material itself, which is liable to cause trouble. With high voltages, however, the conditions may be quite different. With some insulating materials, the dielectric strength may be so affected by long continued high temperatures that the insulating quality becomes insufficient. This has a direct bearing on large capacity, high-voltage turbo-generators.

In the problem of insulation, certain difficulties have been encountered in large turbo-generators, which, while they would have developed eventually in other large machines, yet became apparent more quickly and prominently in the turbo type, due to the abnormal conditions in its design. The two most prominent difficulties were, first, that of relatively high temperature in the buried copper, already described, and second, the destruction of the insulation by reason of static discharges between the coils and the armature iron.

Due to the fact that the ultimate temperature reached in such machines not infrequently exceeds the safe limits for insulation of the fibrous or cellulose type, such insulations will show deterioration eventually in their insulating qualities and their durability. In consequence, with the advent of the larger machines, it became necessary to return to the use of mica for insulating purposes on the buried part of the coil. This type of insulation in the form of mica wrappers, had been used extensively on some of the earlier large capacity, slow-speed generators, but it had not been adopted on large turbo-generators, due principally to the difficulty in applying the very long wrappers for the straight part ot the coil. However, when the gradual deterioration of the fibrous type of insulation was noted in large turbo-generators, the mica wrapper type of insulation was again taken up and, after considerable experiment, was applied successfully for the outside insulation on the straight parts of the coils. This use of mica overcame the deterioration in the insulating qualities of the outside insulation; but for a while it was considered that a fibrous type of insulation was still effective between turns in those coils where there were two or more turns in series per coil. As stated before, the insulating qualities of many fibrous materials will stand up astonishingly well under low voltages, when the material is apparently so greatly heated that it is practically carbonized. Therefore, temperatures which did not carbonize, but simply browned, or darkened, the material, had not been considered dangerous, and undoubtedly many thousands of electrical machines of all kinds are today in operation, in which the insulation is in this condition, and in which no trouble need be expected. For this reason, little or no trouble was expected between turns on the turbo-generators. However, a new condition was encountered in large capacity machines, namely, the insulation between turns, when it became dry and brittle at the higher temperatures, was liable to be injured by the terrific shocks to which the coils were subjected in such machines, in case of a short circuit across the terminals. The insulation would be cracked, or so disturbed that short circuits would occur later, without apparent cause. These short circuits on large machines, most often appeared as breakdowns to ground, even with the mica wrapper insulation on the outside of the coil. Incidentally, several cases were discovered where arcs had occurred inside the coils between adjacent turns, and where they had not yet broken through the outer insulation to ground. For many months the writer, with his associates, followed up this matter, examining all available coils and windings. Eventually the conclusion was reached that many of the breakdowns to ground had actually started between turns on the inside of the coil. Moreover, as a corroboration, it was noted that in machines with one conductor per coil, the breakdowns were practically negligible. This investigation led to the practise of insulating the individual turns, in each coil, from end to end, with mica tape. After the adoption of this practice, it is noteworthy that the breakdowns to ground practically disappeared, although the outside insulation to ground had not been changed in type or thickness.

Many improvements have been made in recent times in the application of this mica insulation. One of these is the Haefely process, developed in Europe, but now being used extensively in this country. By this process, the mica wrappers are so tightly rolled on the coil that practically a solid mass of insulation, of minimum thickness and greatest heat conductivity is obtained.

By means of the mica insulation, the temperature difficulties in general have been entirely overcome, and a durable and non-deteriorating construction, from an insulation standpoint, has been obtained with the temperatures which appear to be more or less inherent in the large, high-speed turbo-generators.

The second trouble, namely, that due to static discharges between the armature copper and the iron, was also encountered to a certain extent, on some of the earlier machines. It was found that these discharges were apparently "eating" holes, or even grooves, through the outside insulation of the armature coils. This effect was most pronounced at the edges of the air ducts and at the ends of the armature core, where edges were presented by the iron. After a long period, the holes or grooves would become so deep that the insulation was weakened or ruined.

This was a very disturbing condition, when it was once fully recognized and appreciated. Again, a comprehensive investigation was made to discover a cure for this difficulty. Various types of machines and windings were examined. It was noted that the action was a function of the voltage of the machine, but was noticeable, in some cases, at relatively low voltages. During the course of the investigations, it was noted that where mica wrappers were used with an outside layer of tape, the " eating away " extended only through the outside wrapping in as far as the mica, and that no apparent effect at the mica was visible. Even when examined with a very powerful microscope, no evidence of any puncture of the mica was found, in any case. These investigations naturally led to the conclusion that the most suitable remedy for the trouble was the use of mica insulation, which was also a remedy for the temperature conditions. This is one of the rare cases in large turbo-generators where two desirable conditions do not conflict with each other. The mica insulations on the buried part of the coil has now been very generally adopted in this country on high-voltage machines, whether of the turbine-driven, or any other type.

This static trouble was considered so serious at one time that low voltage practice with step-up transformers was adopted by some manufacturers as the safest course, until something positive in the way of a remedy was proved out. This trouble promised to be one of the most serious encountered in high-voltage generator work, and even threatened to revolutionize practise in winding generators for the higher voltages. However, as consistently advocated by the writer, the use of mica, suitably applied, appears to have entirely overcome this trouble, as evidenced by several year's experience, and all indications now are that there need be no fear from static discharges on windings of 11,000 and 13,000 volts. Even in the 11,000-volt New Haven generators with one terminal grounded, which gives the equivalent of a 19,000-volt, three-phase winding with the neutral grounded, the mica insulation appears to be successful and durable.

ROTOR INSULATION

In most of the early turbo-generators, the rotor winding in the slots was insulated with fibrous material, " fish paper " and " horn " fiber having the preference. One of the difficulties in the rotor is that the insulation between the winding and the slot is liable to be crushed or cracked by the high centrifugal forces. In the earlier insulations, before fish paper was used, it was found that even at very moderate temperatures, the insulation got dry and brittle, and cracked readily. Fish paper, or horn fiber, was then adopted pretty generally. Such material apparently stood much higher temperatures than the ordinary fibrous insulations. However, experience also showed that eventually this also became brittle, and was liable to be cracked, and then displaced, due to the centrifugal forces. There is always the possibility of a small amount of movement in the field coils when a machine is being brought up to speed, and this movement, in itself, may eventually damage the insulation if it is at all brittle.

As the capacities and speeds of turbo-generators were increased and the space limitations for the rotor windings became more pronounced, the resulting higher normal temperatures led to the adoption of mica for the insulating material in the slots with either mica or asbestos for the insulation between turns. As the voltage between adjacent turns is always extremely low, what is needed is really a durable separating medium, rather than an insulation, this medium being one which will not become crisp or brittle at fairly high temperatures. Asbestos has served for this purpose very effectively, and even has some advantages over mica, as the latter must be applied in relatively small pieces in the form of strap or tape, and the individual pieces are more readily displaced or shifted than is the case with asbestos. Some very severe tests have been made in order to determine the possibilities of such rotor insulation. In one case, a turbo rotor thus insulated was run at full speed for over 40 hours, with such a current that the rise by resistance in the rotor copper was about 250 deg. cent. It was the intention to continue this test very much longer, but the conduction of heat from the winding to the core, and thence through the shaft to the bearings, was such that finally the bearings became overheated and gave out. After this test, the winding was carefully dismantled, and no evidence of any injury to the insulation could be discovered. Of course, such temperatures are not recommended in turbo rotor practice, but this was simply an attempt to find a temperature limitation. If a designer wants to find the facts in any apparatus, he will obtain the most valuable information if he operates the apparatus up to the point of destruction. He thus fixes a limit which he must keep below.

The use of mica, or mica and asbestos, on turbo rotors has been very generally adopted in this country at the present time, and it may be said that, within the writer's experience, no case of destruction of one of these windings through heating, has come to his notice, although a great number of them have been in service for a relatively long time. In many of the older machines with fish paper insulation in the rotors, the conditions of ventilation and the normal ratings of the machines were such that the maximum temperatures in the rotor windings were relatively much less than in present practise. It may therefore be said that the use of mica in the rotor has been largely due to the introduction of the larger capacities and higher speeds.

LOSSES IN TURBO ALTERNATORS

The total iron and copper losses in a large, high-speed turbo-alternator are in general no higher than in a corresponding capacity low-speed machine.

As far as the iron losses are concerned, no further comment need be made than that the magnetic flux densities in general are somewhat lower than in lower speed machines of same frequency, and therefore the losses per unit volume of material are no larger.

The total armature copper losses in turbo-alternators, as a rule, are considerably smaller than in corresponding capacity machines of the moderate or low-speed types. This is due partly to the use of a smaller total number of conductors, and partly to a lower current density in the armature conductors. As brought out before, in a narrow core machine, a considerable portion of the buried copper heat may be conducted lengthwise of the conductor into the end winding, and there dissipated into the air. In the turbo-generator, with its much wider core and greater distance from the buried copper to the end windings, a smaller percentage of the buried copper heat will be conducted into the end windings. To partly compensate for this, it is usual to work the armature copper in the turbo-generators at a lower current density, and therefore at a relatively lower total copper loss. This is somewhat of a handicap in the economical design of the generator, as extra space is thus required for the armature winding. In some of the earlier machines, the armature conductors were made of solid copper bars of relatively large section, partly for stiffening or bracing the end windings, as will be referred to later. With these solid conductors there was a very considerable loss in the buried copper due to eddy currents. To compensate for this, the armature conductors were made very large in section, so that the current density, due to the work current alone, was very low compared with practise in other types of machines. On account of the comparatively large section of armature conductors, the conduction of heat from the buried copper to the end windings was relatively large. In some of these earlier, large capacity machines, the nominal current density in the armature conductors was so low, and the section of conductors so great, that the total buried copper loss, due to the work current, could be carried from the buried part of the coils into the end windings with a comparatively small drop in temperature, so that, if there had been no eddy currents present, the buried copper would have shown less rise than the iron. Any considerable rise which occurred was thus chargeable to eddy currents in the buried conductors, rather than to the work current. While such construction was fairly effective for the purpose, yet it was decidedly uneconomical in design, as indicated before. In fact, with later proportions and methods of design, the safe outputs of some of the earlier machines could easily be 50 to 75 per cent greater, largely on account of elimination of eddy currents and improvement in methods of dissipating heat from the end windings. In many of the older machines, the ventilation of the end windings was not nearly as effective as in modern types, due principally to the form and arrangement of the end connectors. Usually air spaces were allowed between adjacent coils, although, in some instances, these were so small as to give but little benefit. Moreover, in many cases, the type of end winding employed rendered these air spaces between coils rather ineffective, unless special means were taken to deflect the air between the coils. With later constructions, the end windings lie more or less across the path of the ventilating air, and there are ample openings between the coils, so that a very considerable part of the ventilating air will actually pass between the coils of the end windings in such a way as to give the maximum possible ventilation. When it is considered that the total armature copper loss may be only 20 per cent of the total stator loss, it will be seen that an excessive amount of air is not required when the end windings are properly arranged for most effective ventilation.

Much effort has been expended in eliminating or reducing the eddy current losses in the buried copper of large turbogenerators, as well as in other types of large capacity alternators. These eddy currents are due to two sources, namely, the alternating magnetic flux across the slots due to the armature ampere turns per slot, and secondly, the magnetic fringing from the rotor pole face into the open armature slots. In some instances, tests have indicated that the local e.m.fs. set up in the armature conductors by the flux through the slot opening is very considerably greater than those due to the flux across the slot. Obviously, with partially closed slots, this fringing into the top of the slot should be practically absent.

The simplest remedy for the eddy currents set up by these local e.m.fs. is to sub-divide the conductors into a number of wires or conductors in parallel, so arranged or connected that the local e.m.fs. oppose and, to a great extent, balance each other. This opposition may be obtained by special arrangement of the conductors in each individual slot, or parallel conductors in the two halves of a complete coil may be connected in opposition to each other. Some of these arrangements do not completely balance the opposing e.m.fs., but they include the resistance of the complete coil in the eddy current circuit, so that the eddy losses are not only very materially reduced, but they are distributed over the entire coil, including the end windings, which condition, in itself, represents a very material improvement.

PROTECTION AGAINST FIRE

An important problem connected with the insulation of large turbo-generators, is found in the fire risk, or danger of destruction of the end windings due to starting an arc at some point. On account of the tremendous ventilation in such machines, a fire, if once started, may quickly ruin the entire end winding. An extended investigation was made, with a view to providing an insulation which would not burn rapidly. Among other tests, the end windings were finished on the outside with an asbestos covering or tape. However, such tape requires some sort of sealing varnish, or material to fill its pores, to keep it from absorbing moisture or oil. The tests showed that if a fire was once started, combustion would be maintained by the gases liberated by the " gasification " of the varnishes and other material in the end windings, whether the coil was covered with asbestos or not. No covering which was tested appeared to be very effective. Although some outside covering might be found which would be slightly effective in preventing fire from starting so readily, yet, if once started, it appears that a fire can very easily maintain itself in such machines. Eventually, the conclusion was reached that the safest course would be to provide suitable closing doors or valves in the air inlets to completely shut off the incoming air to the machine. In addition, suitable doors on the air outlets, where they can be applied, should also be helpful, by retaining the smoke and burnt gases inside the machine, which thus assist in smothering the flames. The use of fire extinguishers of the gaseous type will usually be rather ineffective, unless the incoming air and ventilation is practically cut off. For instance, with 60,000 cu. ft. (1698 cu. m.) of air per minute passing through a large machine, the addition of a little gas for extinguishing the fire would hardly make any impression. In one instance, in attempting to extinguish a fire, an effort was made to feed the gas in against the ventilating pressure of the fans. Obviously, this would not work, and then a hose was used in order to get enough pressure to counteract the fan action. Although the fire was extinguished, the resultant effect of fire and the high pressure water was that new insulation was required.

REGULATION AND SHORT CIRCUIT CHARACTERISTICS

It has been known for many years to designers, that alternating current generators can give, at the instant of short circuit, a much greater current than that which they will give on continued short circuit. The first emphatic evidence of this, in the writer's experience, was in connection with the first Niagara generators in 1894. Upon short circuiting one of these machines at full speed and normal voltage, the results indicated a current rush so great that it was apparent that it was limited only by the armature self-induction, and not by the so-called synchronous reactance. Later, after being put into actual commercial service, it was found necessary to brace the end windings on these machines. However, at that time, no suitable instrument, such as the oscillograph, was available for determining the conditions on short circuit, and the phenomena did not permit of much experimental investigation.

Similar evidence was found from time to time, as in the first Manhattan Elevated engine type generators, which bent their end windings out of shape on a dead short circuit. But the real possibilities for trouble in this matter did not develop until the large capacity turbo-generators came into use. In these machines, the armature ampere turns per pole are so high, compared with moderate speed alternators, that the stresses due to the stray magnetic fields on short circuit are much greater than the natural rigidity of the end windings will withstand. The manufacturer of such apparatus, without data of any quantitative value at hand, did not fully recognize the real weakness in the end windings until disaster overtook them. Even then it was a long and difficult undertaking to overcome the trouble. All kinds of designs of end supports, and various arrangements of end windings were tried, with more or less success. But each new step in the increase in capacity opened up the problem again. It was soon noted that those armature windings which were made up of cable or small wires, suffered most on short circuit, and for awhile there was a tendency on the part of some manufacturers to use heavy, solid conductors to give rigidity in the end windings. This was effective within certain limits, but was very expensive from the design standpoint, as on account of eddy currents in the buried copper. It was necessary to work at a very low current density, which was not economical in winding space.

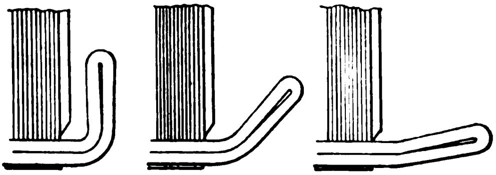

FIG. 20

In this country, the types of armature windings finally narrowed down to the open-slot construction, usually with an upper and lower coil per slot, with the end winding arranged in two layers, similar to d-c. armature windings, or the common induction motor primary windings. This turbo end winding was extended at various angles to the axis of the machine from almost parallel up to 90 deg., as shown in Fig. 20. The principal survivor of these types, is one which extends at some angle between 30 and 60 deg. to the axis. There are several reasons for this,—first, it allows a very substantial bracing to be applied to the end windings. Second, the stray fields around the end windings do not, to any extent, cut the adjacent solid parts, such as the end housings, stator and end-plates, etc. An angular position of approximately 45 deg. seems to be a good compromise on these points. Ample supports, as shown in Fig. 21 can be applied for bracing the windings against movement in any direction. Such end windings are usually braced against metal supports attached to the stator end-plates. The coils are so clamped to the racks, and are so braced against each other that the windings will sustain a dead short circuit across the terminals, even in the largest capacity machines, without injury.

On some recent large turbo-generators, the end windings have been further strengthened by double metal racks between the two layers of windings, so arranged as to securely key these two layers to one another at certain points. Moulded mica troughs are placed around the coils as an extra insulation from the metal racks. By this keying of the two layers to one another, the winding as a whole is stiffened, quite irrespective of any other clamping arrangement. In fact, this is practically equivalent to putting the end windings in rigidly held slots, thus approaching the conditions which obtain in the buried part of the coil.

In order to limit the momentary short circuit current, the armature reactance is now usually made as large as the condition of the design will permit. This naturally means high ampere turns per pole, which in turn means high synchronous reactance, and consequently poor inherent regulation of the machine, especially on inductive loads. This can be illustrated by the following example: Assume a 5000-kw. unit of an earlier design, which can give 25 times full load current on momentary short circuit. By certain improvements in the design of the armature coils, such as the use of deeper slots, better subdivision of the copper to eliminate eddy currents, improved ventilation and conduction of heat, etc., the capacity of the machine is assumed to be increased to 10,000 kv-a., the number of armature turns remaining the same as before. It is evident that when short circuited, the revised machine will give the same total current as on the former rating, which, however, is only 12½ times the rated current on the new capacity basis. Obviously, the end winding stresses are no greater than before, although the nominal capacity has been doubled, and if it were possible to satisfactorily brace the end windings with the former rating, the same bracing should be effective on the new rating. This illustrates, roughly, what is taking place in later designs, although the steps in the change may not be just those mentioned. Again, in the above example, it is obvious that, with the new rating, the inherent regulation at full load is the same as at 100 per cent overload on the old rating, which means that it is relatively poor. Another way to express this is, that the old rating might give 2½ times full load current on steady short circuit, while the new rating gives 1¼ times.

This condition of poorer regulation is inherent in the newer practise, but is apparently acceptable to the users of such apparatus, for a variety of reasons which do not come within the province of this paper.

CONCLUSION

The foregoing covers, in a general way, many of the problems encountered in large turbo-generators, and defines the situation as it stands at present.

It may be suggested, in connection with the temperature problem, that the high temperatures obtained are due to forcing the construction too far; but, in answer, it may be stated that it is forced no further in this feature than in many others. The whole design has been carried far beyond the most economical construction, from the generator standpoint alone. In fact, the whole machine is more or less a compromise between desirable conditions as a generator, and most economical conditions as part of a combined turbine and generator unit. It may be added that the ultimate limits in construction and capacity will be obtained only when the steam turbine conditions are satisfied, and there are indications that possibly this result is being approached now with the present high speeds.

There is one small consolation in all the confusion of development which has attended the turbo-generator work, in the few years it has been with us, namely, the question of choice of speed has been practically eliminated. For 25 cycles, there remains only one speed, namely 1500 revolutions, with two poles, from the smallest unit up to 25,000 kv-a. as a possible upper limit. For 60 cycles, up to 5000 kv-a., two-pole machines at 3600 revolutions are being furnished, while from this capacity up to 20,000 kv-a. four poles may be used.

It will be evident to any reader of this paper, that the designers of large turbo-alternators have had a strenuous time during the past few years—very much more so than is indicated herein, for their successes, rather than their failures have been discussed. In fact, much of the time they have been working ahead of their data and experience. In presenting this situation from the design point of view, it is hoped that a better and clearer understanding of the turbo-generator problem will be obtained by all who are interested in such apparatus.

A paper presented at the Cleveland Section Meeting of the American Institute of Electrical Engineers, Cleveland, October 23, 1911.

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INDUSTRIAL LIGHTING

BY C. L. ESHLEMAN

The industrial manager strives for three things:

1. Increased output.
2. Improved quality.
3. Decreased cost.

They are the component parts of the word "dividends."

Three elements contribute to the realization of these aims:

1. Efficient labor.
2. Efficient machinery.
3. Efficient lighting.

The importance of these elements can be more fully appreciated when we consider that the absence of any one of them renders the others useless. In other words, labor and machinery without light have no value.

The subject of this paper does not carry with it an obligation to discuss the subjects of efficient labor and efficient machinery. Even efficient lighting is too broad, because it covers the two subjects of:

1. Daylight illumination.
2. Artificial illumination.

A discussion of daylight illumination involves the design and finish of buildings—whether large or small areas, high, medium and low studding, flat, sloping, open and closed ceilings, or saw-tooth roof construction. Although these details affect the location and spacing of lighting units, we must leave them to the discretion of the engineer, architect or building contractor and pass to a discussion of artificial illumination.

We shall endeavor to show, (1) that efficient artificial illumination is necessary, (2) that there are lighting units available for the purpose, (3) how these units may be applied to produce the desired result, and (4) the effect obtained from their use.

EFFICIENCY ENGINEERING OF LIGHT

Efficiency engineering is the science of keeping raw input and finished output as far apart as possible. It is the art of stopping leaks. The writer has been interested in it for several years and thoroughly believes that scientific management is the most important factor entering into the movement for the conservation of our natural resources. Our waste of today will be our dividends of tomorrow.

Efficiency engineering of light is part of this great national movement, the aim being to install an artificial lighting system that will allow a plant to operate at as high efficiency during the dark hours as during the sunlight hours of the day.

Efficiency of the Human Machine. Industrial statistics show that the average cost of all finished products in the United States is one-third labor and two-thirds material.

Increased labor efficiency is therefore a very important factor in considering methods of reducing manufacturing costs. Two things contribute to this efficiency:

1. Machinery and facilities.
2. Will of the operator.

Machinery and Facilities. It is economy to supply the best tools with the best facilities, and among such facilities light stands first. We want to emphasize that point. Light is a tool. It is to the writer's mind the most important tool in the industrial plant. It is a tool by means of which all other tools are run.

In equipping his plant, the modern industrial manager spares no expense in the purchase of up-to-date tools and machinery. The finest punch presses, the best lathes, the most expensive automatics must all be his. But how about the lighting? Strange as it may seem lighting very frequently is an incidental—a matter of secondary consideration.

There will come a time when lighting will be considered first. That time will be when the industrial manager realizes that an efficient lighting installation will earn greater dividends on its cost than any other tool or machine in his entire plant.

Will of the Operator. The human machine must have the will to work, as well as the facilities. The conscious will is largely the result of wages; the subconscious will depends upon interest in the work, contentment with conditions and physical health. The two latter conditions are largely dependent upon light.

These statements are true and must surely appeal to the progressive industrial manager. Yet when you approach him on the subject of a new lighting system, he tells you that they sound good in the theory, but he wants to see the dollars and cents side of the question. It is easy enough to produce figures that show a large saving in current by the installation of high efficiency lamps in place of antiquated low efficiency types, but the trouble comes when we try to reduce human efficiency to dollars and cents. It is the writer's aim in the future to devote as much time as possible to a comprehensive study of this subject, with the idea of reducing the intangible benefits of good lighting to a definite basis.

In spite of the difficulties referred to, it has been possible to collect the following interesting and convincing data:

a. Modern industrial plants have machinery arranged so that raw material is taken in at one end and finished produce taken out at the other. There is a natural sequence of operations; that is, working without lost motion. Often the lighting is inadequate, or so poor, that this sequence is broken. That means a tie up of the entire plant and an undisputed waste. As an example of this, an estimate furnished by one of the large paper mills recently, indicated that the loss on the output for six minutes is more than the cost of the lighting for 24 hours.

b. A recent study of shoe factory conditions, revealed the fact that they are miserably lighted. For example, a man operating a channeling machine in the sole leather room, told the investigators that he was unable to do any channeling after dusk, so spent his time in grinding knives, etc. This work could have been done by a comparatively low priced boy.

c. As night comes on, it is natural for us to relax and slow down in our work. Darkness produces a weariness that we cannot overcome. As explained before, ideal lighting is that which merges day into night with the least change in intensity.

In poorly lighted factories bodily fatigue steals over the workman, and if he continues to work, his efficiency is further reduced by eye fatigue.

Pages could be written on eye fatigue and what it does toward reducing the workmen's efficiency. In a word, it is one of the most powerful and cunning enemies to health and happiness that civilized human beings know.

The question of cost of light is wholly inconsiderable as compared with the efficiency of the workman. Even if used during the entire working hours of the day, it will not represent more than one-half of one per cent of the workman's wages.

d. A few personal experiences that bear on this subject are significant.

After leaving college, the writer entered the shop course of one of the large electrical manufacturers. Daylight conditions in the factory buildings were good, but the artificial lighting was not at all conducive to human efficiency. Winding coils on piece work basis, he could earn $2.00 per day. Later when changed to night shift, he could earn only $1.10 during a corresponding number of hours. The same condition held with other men, so that we requested to be placed on hourly pay. We did not think about efficiency engineering of light at that time and apparently the foreman did not, because there was no change and the company continued to run that department at 55 per cent efficiency. In addition to that, it is recalled that only about 5 per cent of the coils wound by daylight failed under high-voltage insulation test, while 10 to 15 per cent of those wound at night were returned for rewinding.

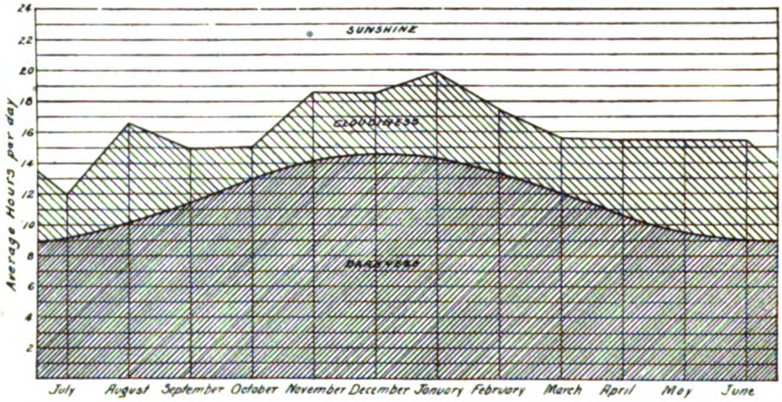


FIG. 1

While testing motors and generators, it must be confessed that he frequently fell asleep sitting on the bedplate of the machine that he was testing. He was willing and anxious to give the company the best that he had in him but the light was so poor that eye fatigue simply put him down and out.

Later, while in the sales department, he asked the foreman of one of the manufacturing departments to do some night work on rush orders. The foreman stated that he would like to accommodate him, but that the last time he worked nights, he found at least a half dozen empty whiskey bottles hidden in the corners. Possibly it was a case of poor light driving them to drink. The same deplorable conditions obtain in many of our industrial plants today.

c. Industrial employes are primarily interested in two things, wages sufficient to properly feed and clothe themselves and pleasant working conditions. "Light lightens labor" and we must admit goes a long way toward furnishing the latter requisite. If we keep our help working at high efficiency, our output in quality and quantity is sufficient to warrant our paying a good livable wage. Good light seems therefore to be a panacea for many labor troubles.

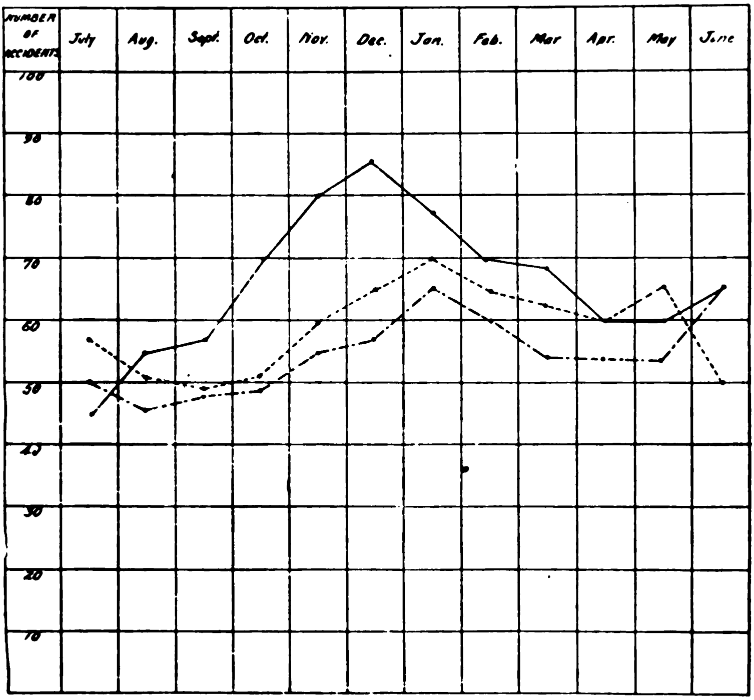


FIG. 2

THE EFFECT OF GOOD ILLUMINATION UPON SAFETY

Fig. 1 shows the average hours per day of sunshine, cloudiness and darkness for each month of the year in New York City. Fig. 2 shows the seasonal distribution for three successive years of 700 deaths annually from industrial accidents reported from an area embracing 80,000 plants. Note carefully that the death rate is practically twice as high during the dark December and January days as it is during the light June and July days.

In a book entitled " Prevention of Industrial Accidents " published by an insurance company of New York, the following statement appears: " Statistics show that the greatest number of accidents occurs during the months of diminishing light." A comparison of the above diagrams shows in a very striking manner the relation that good illumination bears to the number of accidents which occurs in industrial plants at the present time. These two charts can mean only one thing; that at the present time proper illumination is not furnished to safeguard suits against accidents.

The Manufacturers Association states that in the United States alone, 500,000 avoidable accidents have occurred in one year, and it is claimed by the authorities who have made a study of safeguards for the benefit of employes, that 25 per cent of these accidents were caused by poor illumination. Now while a good deal is being said in regard to suitable safeguards to protect lives and limbs of employees, it is time that some definite step is taken towards the adoption of good illumination, as one of the economical safeguards against accidents.

The above charts and the statement coming from one of the largest insurance companies, should sufficiently impress industrial managers with the fact that a suitable amount of light is as essential to the safety of their employees as any of the safeguards that have already been applied to belts, pulleys, etc. The costs and damages incurred by these accidents when added to the lighting bill, as they rightly should be, increase it out of all proportion to the cost necessary to prevent such accidents through the medium of good illumination. Every mill owner and operator has had his own little experience along this line. Therefore, nothing more need be said regarding the necessity of taking every step possible for the future protection of himself financially, and his employees physically.

Aside from the humanitarian phases of this question, industrial plants will find themselves in a most embarrassing position when employers' liability acts, such as have been passed by the New Jersey legislature are enacted generally throughout the United States.

AVAILABLE LIGHTING UNITS.

Electric lighting is considered standard for all industrial purposes. Two general classes, incandescent lamps and arc lamps are available and may be outlined as follows:

Incandescent lamps
- Carbon
- Gem
- Tantalum
- Tungsten

Arc lamps
- Enclosed
- Flame
- Luminous

Carbon incandescent lamps and enclosed carbon arc lamps were standard for industrial lighting from the early nineties to about 1907. About that time high efficiency incandescent lamps made their appearance and have been growing in popularity ever since.

Even though many of the older forms are still being sold and used, it can well be said, for the purposes of this paper, that two forms of electric illuminants are now standard:

High efficiency incandescent (tungsten) and high efficiency arc lamps (flame and luminous).

So much of a convincing nature has been said and written about the saving in current cost by using high efficiency units over low efficiency, that it would be superfluous to enter into a detailed discussion of their respective merits. We are safe in assuming, however, that wherever the current cost is one cent per kw-hour or above, it will be economical to install high efficiency lamps.

Neither will space permit a detailed outline of the relative operating cost of incandescent lamps and arc lamps. The selection of either form of illuminant depends upon the nature of the work to be done. Both have their place, and when it comes to relative operating cost, there is but little difference. Incandescent lamp adherents claim that the tungsten lamp has lower operating cost than arcs, while arc lamp adherents claim that the flame and luminous arcs are more economical. Where doctors disagree, the industrial manager must decide. Technically, however, both are correct, because, as will be outlined later, both have a definite function to perform and in many cases, the two lines dovetail.

With the development of high efficiency lighting units, it became necessary to deal with light sources having higher candle power. The units had to be spaced further apart, they had to be suspended at greater heights and, above all, the extremely brilliant light sources had to be covered to prevent injury to the eyes of those working beneath.

Reflectors of different forms were developed, not only to protect the operator's eyes, but to direct the light where it was most needed. For commercial lighting, glass reflectors are standard, while for industrial purposes, steel reflectors are most commonly used.

LOCATION AND SPACING OF UNITS

This subject at once suggests the three general classes of industrial illumination, viz.: (1) general illumination, (2) specific illumination, and (3) composite illumination.

1. The first class is used where a more or less even intensity of light is desired over the entire floor area. For this class of lighting, high candle power incandescent lamps, 150 candle power and up, or high candle power arc lamps should be used.

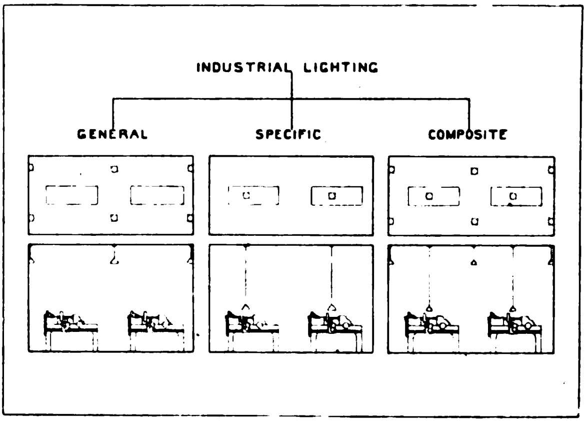
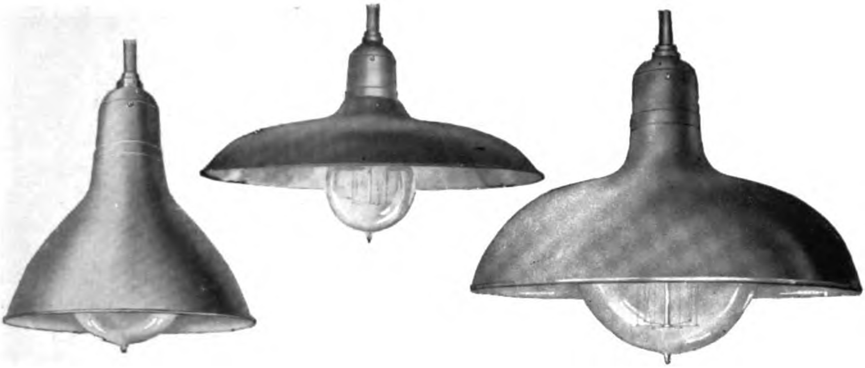


FIG. 4

2. The second class deals with individual lighting or where a higher degree of illumination is desired at the working plane than would be practical or economical for the entire floor area. Specific illumination is provided by installing low candle power units applied directly to the various types of machines as, for example, lathes, sewing machines, silk knitting machines, etc.

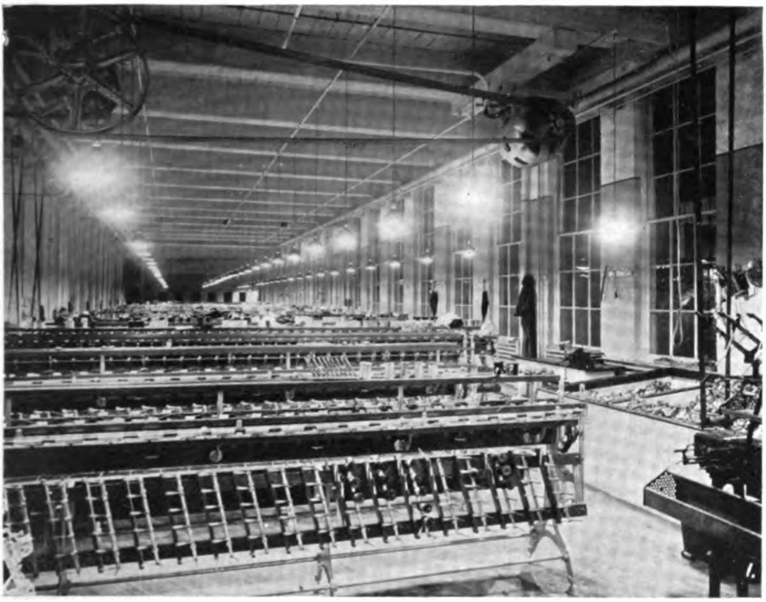
3. Composite lighting embodies both the general and specific, where low candle power units are employed for close work and high candle power units to light the entire area.

General illumination or composite illumination will be found



[ESHLEMAN]

FIG. 3.—SCIENTIFIC STEEL REFLECTORS



[ESHLEMAN]

FIG. 5.—WINDING DEPARTMENT, SILK MILL

The twenty crow winders of the soft silk department are lighted in groups of two. One 60-watt tungsten lamp, with intensive steel reflector, is placed half way between each two machines at a uniform height of 7 ft. 6 in. (2.28 m.) above the floor

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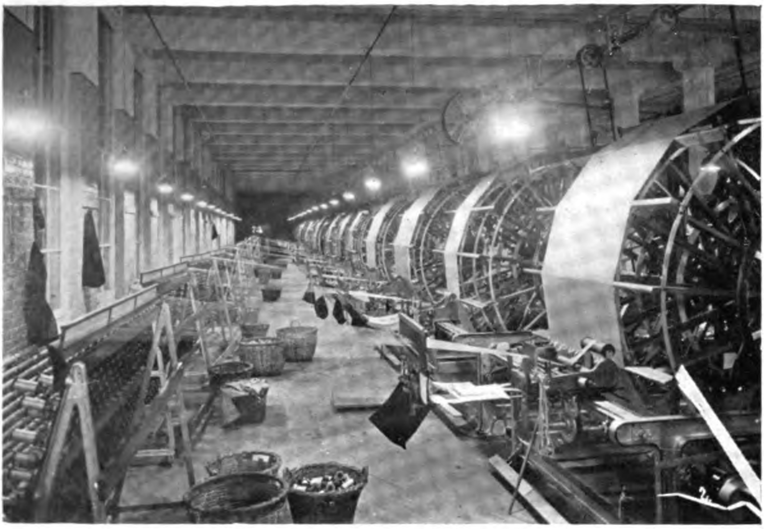
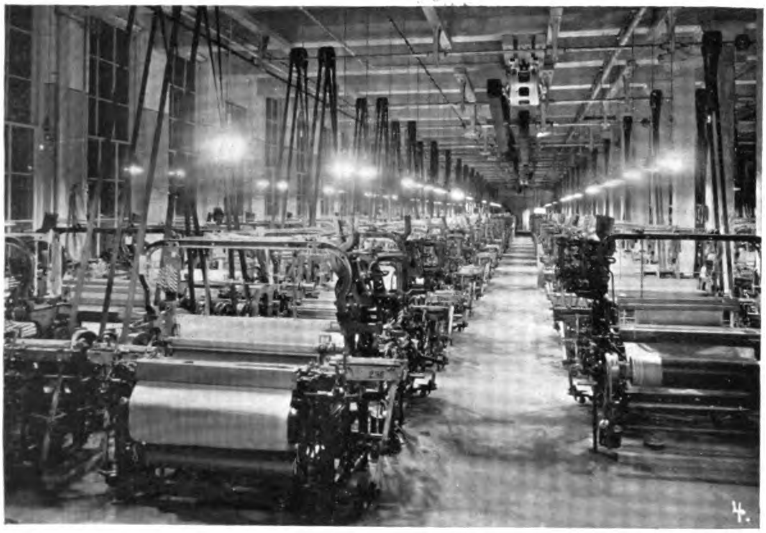


[ESHLEMAN]

FIG. 6.—WARPING DEPARTMENT, SILK MILL

Three units, consisting of 60 watt tungsten lamps and intensive steel reflectors, are used for each machine. One unit placed on the bobbin rack, one in front of the reel and one at the rear. The mounting height of the units is 7 ft. 6 in. (2.28 m.) above the floor. The entire length of the warp is uniformly lighted.



[ESHLEMAN]

FIG. 7.—WEAVE SHED, SILK MILL

The weave room is divided into two parts, each occupying one-half of the second floor. In each, there are 200 looms. Fig. 7 shows one aisle in each of these halves. The lighting of the looms is accomplished by placing one 60-watt tungsten lamp equipped with intensive steel reflector over the loom in the space between the lathe and the harness. A second unit is suspended in the warp alley, midway between the backs of two adjacent looms In this way these looms are lighted by two 60-watt lamps. The height of the lamps is 7 ft. 6 in. (2.28 m.) above the floor.

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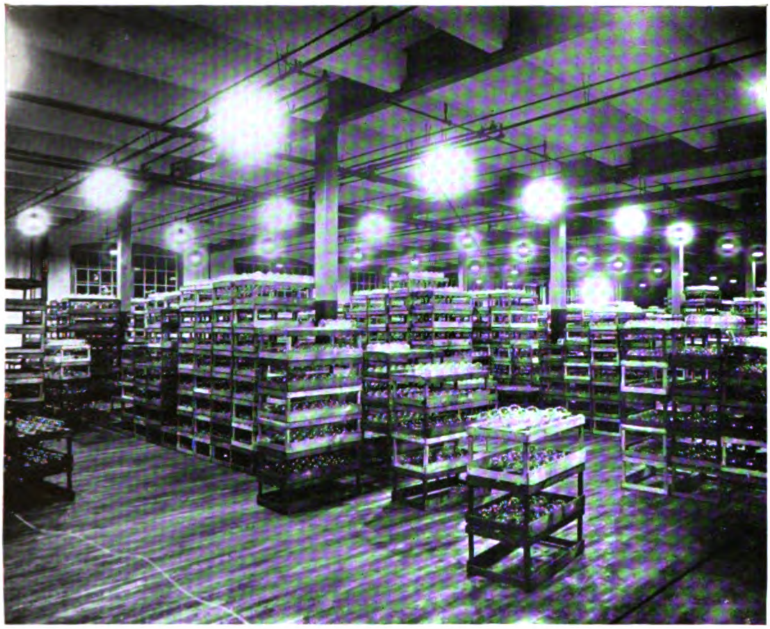
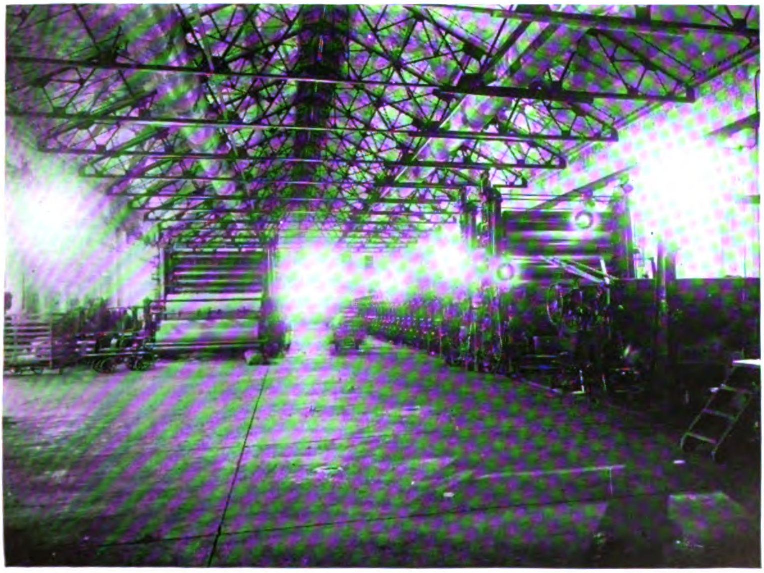


[ESHLEMAN]

FIG. 8.—LAMP WORKS OF THE NATIONAL ELECTRIC LAMP ASSOCIATION, LIGHTED WITH 60 AND 100 WATT TUNGSTEN LAMPS FITTED WITH INTENSIVE ENAMELED STEEL REFLECTORS



[ESHLEMAN]

FIG. 9.—THE MARATHON PAPER MILLS, LIGHTED BY REGENERATIVE FLAMING ARC LAMPS

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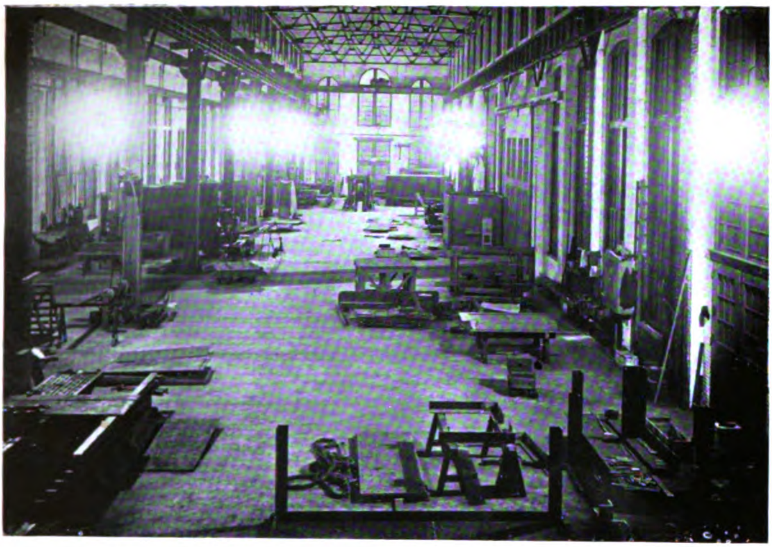

[ESHLEMAN]

FIG. 10.—YORK SAFE AND LOCK COMPANY, LIGHTED BY REGENERATIVE FLAMING ARC LAMPS

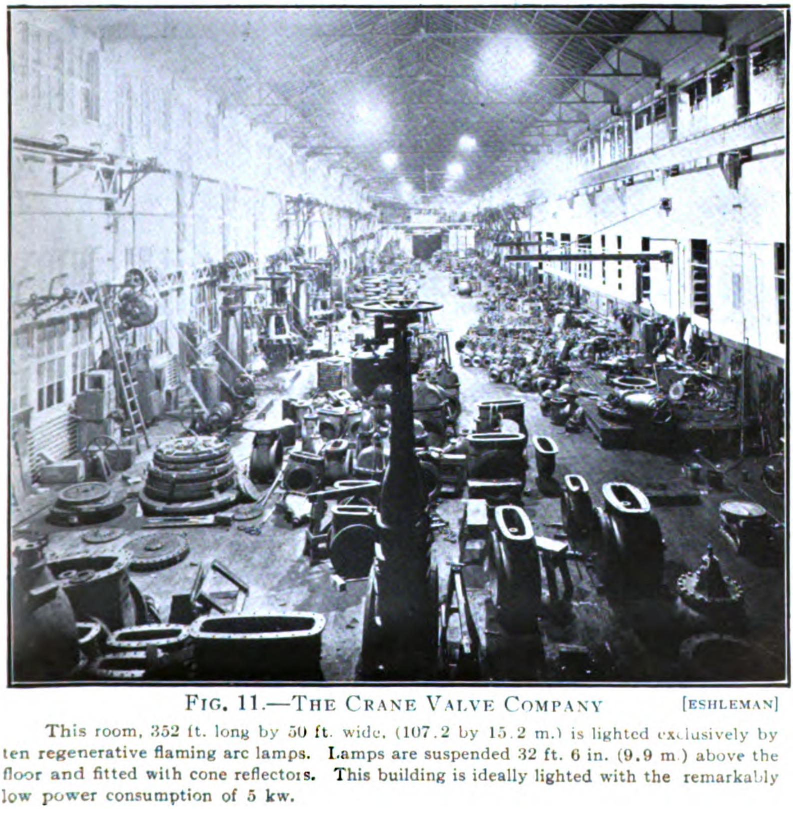

FIG. 11.—THE CRANE VALVE COMPANY [ESHLEMAN]

This room, 352 ft. long by 50 ft. wide, (107.2 by 15.2 m.) is lighted exclusively by ten regenerative flaming arc lamps. Lamps are suspended 32 ft. 6 in. (9.9 m.) above the floor and fitted with cone reflectors. This building is ideally lighted with the remarkably low power consumption of 5 kw.

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to cover most industrial conditions. General illumination is most economical and should be used wherever practicable. By avoiding specific illumination it is possible to reduce wiring costs, unsightly drop cord suspensions and the lighting unit is not subjected to handling and derangement by operators. This latter prevents three things:

1. Breakage of lamps.
2. Soiling and breakage of reflectors.
3. Time wasted by operators in adjusting and handling the drop light.

It is impossible in this limited space, to treat the subject of spacing and location of units in more than a general way and point out a few concrete examples of good practise, including some general rules that may be followed to advantage.

Let us take for example, high studded rooms, such as erecting bays, locomotive works, shipbuilding plants, iron and steel foundries, center bays of machine shops and the like. In such places the most satisfactory and economical results may be obtained by the use of large high candle power units placed above cranes and as far out of the normal line of vision as possible. In such cases it is necessary to use more or less concentrating reflectors in order to cut out the waste light on the side walls and raise the foot candles on the working level. By large units, we refer to flame arcs, luminous arcs, 500 watt tungsten, or in fact, any high efficiency unit having a current consumption of approximately 500 watts.

Rooms of moderate height ranging from 12 to 15 ft. (3.6 to 4.5 m.) such as we find in cotton, wool, silk and similar mills, small machine shops or machine shop galleries, clothing manufacturing establishments etc., can be lighted to advantage with either large or small units or a combination of both, depending upon local conditions. Where the studding is relatively low, say less than 12 ft. (3.6 m.) small units, such as the 100, 150 and 250-watt tungsten lamps usually give the best results.

In every case, preference should be given to the largest possible unit consistent with sufficiently good distribution for the particular purpose. By minimizing the number of lamps, we cut down the cost of wiring switching, and the maintenance cost of the units.

Briefly, the relative cost list price, 1300 hours life of five 100-watt lamps on a 4000-hour year, is $20.76, while the cost of one 500 watt lamp for the same period is $16.92, showing a sav-

TABLE I.—TUNGSTEN LAMP INSTALLATIONS

Ceiling or girder ine height*	Character of surroundings	Size of lamp	Spacing distance*	Mounting height above floor*	Watts per square foot§	Class of work
		Manufacturing Spaces				
8′1″	Light ceiling, no walls	60 watt	8′0″ x 8′0″	7′ 6″	0.96	Winding work
9′0″	No ceiling, dark "	100 "	8′0″ x 8′6″	8′ 6″	1.60	Bench work—flat
11′1″	" " " "	100 "	8′0″ x 8′9″	10′ 3″	1.56	Bench work
11′9″	Dark ceiling, no "	100 "	8′0″ x 9′6″	11′ 0″	1.56	Machining
11′9″	" " and "	100 "	8′0″ x 8′9″	11′ 0″	1.56	Machine work
12′0″	" " no "	100 "	8′0″ x 8′0″	11′ 3″	1.54	" "
12′0″	" " " "	100 "	7′0″ x 8′0″	11′ 3″	1.67	" "
12′0″	" " " "	100 "	7′0″ x 8′0″	11′ 3″	1.79	Bench work
12′6″	" " " "	100 "	8′0″ x 10′0″	12′ 0″	1.25	Machine work
13′8″	" " and "	100 "	8′0″ x 8′6″	12′10″	1.54	" "
16′0″	No ceiling, dark "	100 "	8′0″ x 8′9″	14′ 6″	1.61	Winding work
16′0″	" " light "	100 "	8′0″ x 10′0″	15′ 2″	1.30	Rough work
16′0″	" " " "	250 "	11′6″ x 16′0″	15′ 2″	1.23	Painting machines
16′0″	" " dark "	250 "	10′0″ x 12′0″	15′ 2″	1.76	Fine die work
16′0″	" " " "	250 "	13′0″ x 14′0″	15′ 2″	1.18	Bench work
24′9″	Dark ceiling, no "	250 "	10′0″ x 12′0″	21′ 3″	1.85	Fine assembly work
24′0″	" " " "	250 "	10′0″ x 12′0″	21′ 3″	2.00	Machine work
24′9″	" " " "	250 "	11′0″ x 12′0″	21′ 3″	1.66	Testing
25′2″	" " " "	250 "	10′0″ x 12′0″	21′ 7″	2.35	"

*One ft. = 30.5 cm. One in. = 2.54 cm. §One sq. ft = 0.0929 sq. m.

ing of approximately 24 per cent. In all cases the lamps should be supplied with proper reflectors, placed as high as possible and every effort should be made to shield the direct light from the eyes of the operators without, of course, sacrificing too much in foot-candles on the working level.

The location of lighting units can be summarized as follows:

1. Large units for high studded rooms, small units for low studded spaces.
2. Place lamps above the crane and always as high as conditions permit, using in every case suitable reflectors.
3. Select the largest lamps consistent with sufficiently good distribution for the particular purpose.
4. Where the floor space is large and the work rough, use moderate general illumination, and for the same condition, with fine work, add local lights at the tools. Where there are a great number of small machines in a relatively small space, general illumination should be used. For processes on machines turning out particularly fine work, individual lights will probably be required.
5. Protect the employees as much as possible from direct rays of light. Cut down the intrinsic brilliancy and secure good diffusion.

Table I gives data of the lighting plant of a large factory. The lighting intensities given in Table I are rather too high for ordinary purposes but the table is given principally to show the seven heads that should be considered in planning an industrial lighting installation.

TABLE II.—FOOT-CANDLE INTENSITIES RECOMMENDED FOR VARIOUS CLASSES OF SERVICE.

Arcade (in addition to light from show windows)	1.0
Armory	2.0
Art gallery (walls)	5.0
Auditoriums	2.0
Automobile—	
Garage, large	2.0
Garage, small	1.0
Showroom	5.0
Storage room	1.0
Ball room	2.0
Bank (general)	3.0
Bar room	2.5
Barber shop	3.0
Bath (public)—	
Dressing rooms	1.0
Swimming pool	2.0
Billboard	8.0
Billiard room—	
General	1.0
Table	5.0
Bookkeeping	5.0
Bowling alley—	
Alley	1.0
Pins	4.0
Runway and seats	1.5
Cafe	2.5
Card room (tables)	2.0
Carpenter shop—	
General	2.5
Machinery	4.0
Cars—	
Baggage	1.0
Day coach	2.0

Cars (*continued*)	
Dining	2.0
Mail	7.0
Pullman	2.0
Street	2.0
Corridors	0.6
Courts—	
Handball	7.0
Squash	7.0
Tennis	7.0
Courtroom	2.0
Church	2.0
Dance hall	2.0
Depot—	
Baggage room	1.0
Train sheds	1.0
Waiting room	2.0
Drafting room	8.0
Engraving	10.0
Factory—	
General lighting (where individual drop lights are provided)	1.5
General lighting (where no individual lights are provided)	4.0
Local bench illumination	4.0
Fire stations—	
At alarm	3.0
At other times	1.0
Foundry	3.0
Garage	2.0
Gymnasium	2.5
Hallways	0.6
Hospital—	
Corridors	0.5
Operating table	12.0
Wards (with no local illumination supplied)	1.5
Wards (with local illumination supplied)	0.5
Hotels—	
Bedroom	1.5
Corridor	1.0
Dining room	2.0
Lobby	2.0
Writing room	3.0
Lavatory	3.0
Laboratory	3.0
Laundry	2.0
Library—	
Stock room	1.5
Reading room (with no local illumination supplied)	3.5
Reading room (with local illumination supplied)	1.0
Lodge room	2.5
Lunch room	2.0
Market	3.0
Mechanical work (fine)	5.5
Moving picture theatre	1.5
Museum	3.0
Office—	
File room	3.0
Desk	4.0
General (no drop lights)	4.0

Office (*continued*)	
General (with drop lights)	1.5
Vault (safe)	3.0
Vault (storage)	1.0
Pattern shops	4.0
Pool room (general)	1.0
Pool table	5.0
Power house	2.5
Postal service	7.0
Press room	4.0
Reading (ordinary print)	2.0
Reading (fine print)	2.5
Residence—	
Porch	0.2
Porch (reading light)	1.0
Hall (entrance)	0.7
Reception room	1.5
Parlor	1.5
Living room	1.5
Library	2.0
Music room	2.0
Dining room	1.5
Pantry	2.0
Kitchen	2.0
Laundry	1.5
Hall (upstairs)	0.5
Bedroom	1.5
Bathroom	2.0
Furnace room	0.5
Storeroom	0.5
Restaurant	2.0
Rink (skating)	2.0
Rug rack	15.0
Saloon	3.0
School—	
Assembly room	2.0
Classroom	2.5
Cloakroom	0.8
Corridor	0.8
Drawing	5.0
Laboratory	3.0
Manual training	3.0
Office	2.5
Study room	2.5
Sewing (light goods)	4.0
Sewing (dark goods)	8.0
Shipping room	1.5
Show window—	
Dark goods	20.0
Light goods	8.0
Medium goods	16.0
Sign	8.0
Spinning mills	2.0
Stable	1.0
Stereotyping	4.0
Stock room	1.0
Store—	
Art	4.0
Baker	3.0
Book	3.5
Butcher	3.5
China	2.5
Cigar	3.0
Clothing	6.0

Store (*continued*)	
Cloak and suit	5.0
Confectionery	3.0
Decorator	3.0
Department (see each department)	
Drugs	3.0
Dry goods	4.0
Florist	3.0
Furniture	5.0
Furrier	5.0
Grocery	3.0
Haberdasher	5.0
Hardware	4.5
Hat	4.0
Jewelry	3.5
Lace	3.0
Leather	3.5
Meat	3.5
Men's furnishings	3.5
Millinery	4.0
Music	3.0
Notions	3.0
Piano	4.0
Post cards	3.0
Shoes	3.5

Store-Department (*continued*)	
Stationery	3.5
Tailor	4.0
Tobacco	3.0
Street—	
Business (not including light from show windows and signs)	0.5
Country roads	0.05
Prominent (in residence districts)	0.2
Residence	0.1
Studio	4.0
Telephone exchange (general)	3.0
Theatre—	
Auditorium	2.0
Lobby	3.0
Typsetting	8.0
Warehouse	1.0
Wharf	1.0
Weaving—	
Cotton, light colors	2.5
Cotton, dark colors	4.0
Wool, light colors	3.0
Wool, dark colors	5.0
Silk, light colors	4.0
Silk, dark colors	6.0

Manufacturing conditions vary so greatly that it is impossible to establish definite rules covering all installations. Each installation should be handled on its merits and it should be handled by a competent illuminating engineer. *When the human eyesight is defective, we consult a competent specialist. When our factory eyesight is defective, we should consult an experienced light specialist.*

CONCLUSION

The aim of this paper has been to show four things:

1. That efficient artificial illumination is necessary.
2. That there are lighting units available for this purpose.
3. The application of these units to produce the desired results.
4. The effect obtained by their use.

In conclusion, we should like to call attention to the possible saving in industrial operation by the proper application of efficient scientific illumination.

Two hundred and fifty thousand industrial plants in the United States have an annual output of $20,000,000,000. Available data shows that an efficient lighting system increases the output from 2 per cent in steel mills to 10 per cent in textile mills and shoe factories. To be ultra-conservative, we will say that there is a saving of only 2 per cent in the annual output of the manufacturing plants of the United States. This means an annual saving of $400,000,000. This enormous sum represents the saving on actual production only and leaves us to conjecture what the saving would be if we took into consideration the improved quality of output and the saving due to decrease in deaths and accidents. Deducting the first cost of installation and maintenance still leaves an almost incredible amount.

Louis Brandeis testified before the Interstate Commerce Commission, Washington, that by scientific management the railroads of the United States could effect a saving of $1,000,000 per day. A careful perusal of the figures given above, shows a saving of more than $1,000,000 per day by an application of the principles of efficiency engineering of " light " to the industrial plants of the United States.

The field is unlimited, the possibilities are almost beyond human comprehension.

DISCUSSION ON "INDUSTRIAL ILLUMINATION AND THE AVERAGE PERFORMANCE OF LIGHTING SYSTEMS" (CLEWELL), AND "THE PROBLEMS OF INTERIOR ILLUMINATION" (JONES), BOSTON, MASS., JUNE 26, 1912. (SEE PROCEEDINGS FOR JULY AND JUNE, 1912.)

(*Subject to final revision for the Transactions.*)

D. McFarlan Moore: Mr. Jones has given us a demonstration which proves the fallacy of attempting to illuminate any interior without giving very careful attention to the matter of shadows. The problems of interior illumination are generally duplex, that is, attention must be given to daytime illumination and night time illumination. There are some instances, however, when it is not desired to produce at night time the same effect as in daytime.

However, our object, generally, is to attain the ideal, and the more diffused the light, the more nearly will it approach daylight conditions. In most apartments it is impossible to arrange for the entrance of daylight from above, and we are compelled, perforce, to use windows, and therefore shadows naturally result. We have just had a demonstration that proves that shadows have their uses and if they are eliminated entirely, the result is not usually desirable to the architect. But the happy mean is right as regards shadows, as well as everything else in this world.

Mr. Jones has also put us all through some rapid-fire visual gymnastics with color. Our final commercial object should be to devise the apparatus of our artificial lighting sources so that these valuable color effects can be produced with the greatest ease.

The ideal method is not by means of colored glasses. A more scientific procedure is to vary, directly, the color of the light source, which can best be accomplished by substituting, for our heated solid conductors, various colored gaseous conductors.

Preston S. Millar: It is very difficult to discuss a demonstration, particularly when it is a good one. One can do little more than compliment the demonstrator and hope that some time he may have an opportunity to see it again.

It seems to me that Mr. Jones' paper sets before this joint meeting of electrical and illuminating engineers the field of illuminating engineering in an excellent manner. It discusses the principles of illuminating engineering and then illustrates their application in a notable installation.

Prominent in that discussion is the comment upon the question of efficacy of lighting, the achievement of certain desirable lighting effects, and efficiency; and Mr. Jones points out that the proper lighting effects must be secured efficiently, if possible, but must be secured inefficiently if necessary. This indicates the importance of the scientific study of these problems and the importance of securing the effects efficiently.

It has been demonstrated that if an illumination installation provides lighting which is at once properly diffused, properly directed, and of a proper color value or intensity, that lighting system becomes expensive, perhaps two or three times more expensive, in both equipment and operation, than it would be if it merely lighted the place, but not properly, from these various standpoints. The question of efficiency, therefore, is of even greater importance when lighting is undertaken in this highly desirable manner. But it is so easy to lose a very large percentage of possible obtainable efficiency by ignoring the optical laws or selection of the proper illuminant, etc., and I have had an instance only recently brought to my attention in which the proper lighting effect was obtained, but most inefficiently, because the optical laws involved and the characteristics of the illuminant were ignored.

I know that Mr. Jones has made a considerable study of these matters, and it seems to me if he had laid a little more stress upon the cost of the experimentation which he has gone through in order to secure the effect he has obtained he would have placed the general illumination problem before us a little more broadly.

Charles F. Scott: With reference to Mr. Clewell's paper, I happened to be associated with Mr. Clewell in the general work on which this paper is based. It was in connection with the lighting of a large factory. Some improvements were to be made. Although a number of us who constituted the lighting committee were reputed to know something about the subject, electrically, and from the standpoint of illumination, we immediately called for experts associated with different companies in the illuminating business, to come and tell us what we ought to do. One of the surprises which came to us in connection with this call for expert opinion was when we found that these engineers could not look at a room and tell us, " You want to put in so many lamps of such a size, and such a kind of reflector—that is the thing to do." The rooms were simple, and of the same size as other rooms which had been lighted, the space to be lighted was no more than is met with in any average case, but no, they wanted to study the conditions, and see what was to be done, and get exact measurements of the room, etc., and go home and study over the proposition for several days before they would give an opinion as to what was the best thing to be done.

A few months later, in lighting one of the offices in this same factory, an office some 20 ft. (6.1 m.) square, we had first the single light in the center of the room, and then a number of individual lights over the desks, but we took out the single light in the center and put in a cluster of four lights, and that made a vast improvement over the illumination given by the single light. We thought that did not go far enough, and put up some smaller lamps, three rows of three lights each, all the lamps to be lighted at once, and had them burning several days, and tried to see which light was best, so that we could get along without the individual carbon lamps, etc. The assistant to the president came round one day and said, "We want to get this place lighted, and if your committee will stop this foolish experimenting you may accomplish something. You look as if you did not know what to do. Ask the people who are using the lights what to do, and then go away and leave it, and we can go ahead and light this factory."

That illustrates the type of man who is frequently met in the work of installing lighting systems. People do not understand these things, and the kind of analysis which Mr. Clewell has given shows in a simple way how the putting up of ordinary lights, with bell-shaped reflectors over them, is not a thing to be done in the abstract, but in the concrete. It is a place where theory and practise do combine, and where different kinds of practise may be combined with theory.

From the demonstration we have seen, we all know it is most obvious, when it is pointed out, that the shadow effect and color effect depend on the direction of light, intensity of light, the color of light, etc. It took a quarter of a century for the electric lamp to realize that it was not to replace the gas jet, but the electric lamp did overcome the use of the chandelier. We have got rid of the chandelier, but still we try to imitate the candles which are a thousand years old; we cannot seem to get away from the old things. We must learn to be illuminating engineering decorators.

In reference to Mr. Clewell's interesting diagram showing the spacing of the lamps and the direction of the light, a rough approximation to what he has there is to divide the space above the plane of the table into cubes and put a lamp at the center of each cube. The height of the ceiling from the floor is 12 ft. (3.6 m.), and if the table is 4 ft. (1.2 m.) high, then the ceiling is 8 ft. (2.4 m.), above the plane of the table, and therefore the lamps should be 8 ft. (2.4 m.) apart, and that is what he has. This rule does not carry out fully, but is a close approximation to what Mr. Clewell's diagram shows.

Not long ago I visited the office of one of the largest lighting companies in this country. The engineer showed me about, and incidentally showed me the lighting in some of the offices. There were two drafting offices. One had indirect lighting and the other was lighted by a wretched type of illumination, the bare tungsten lamps hanging over each desk, about 18 in. (46 cm.) above the desk. It was a remarkable illustration of faulty and criminal illumination, which it is our purpose to do away with, and to educate the people to a knowledge of its shortcomings. I said to the chief draftsman who had charge of both rooms: "I see you have both kinds of lighting here—the indirect lighting and the bare tungsten lamp. Suppose you had to use one room altogether, for the sake of getting work out for the company, if it took eight hours to do a certain piece of work in this poorly lighted room, in how many hours would you expect to do the work in the other room?" He replied, "It would probably take from an half hour to three-quarters of an hour less to do the work in the other room." In other words, there was a gain of from one-half to three-quarters of an hour by having good light. I then asked him the cost of the draftsmen and the cost of the lighting to compare one with the other, and he said that the difference in the cost of the lighting was equivalent to the cost of the draftsmen's services for a period of five minutes in each day, so that if the lighting had been as good in one room as in the other, there would have been a saving of from one-half to three quarters of an hour each day. We ought to realize, therefore, what a great economy there is in efficient lighting.

A. E. Kennelly: In pursuance of the idea which Professor Scott has given, I would like to draw attention to one detail of Mr. Clewell's paper, which is, by the way, a plea for the duster, and shows us that, in illuminating engineering, cleanliness is next to luminescence. The constants are worked out very clearly as to the money value of cleanliness and, of course, they are convincing as a matter of simple arithmetic, from the standpoint of producer and consumer combined. Say it costs one dollar an hour to light a certain hall, if all the light is cut off by dirt, all that dollar is wasted, and if half the light is cut off fifty cents an hour is wasted. An important point was touched upon by Mr. Scott,—the value to the consumer alone, as distinguished from the combination of producer and consumer. Suppose the lighting in a work room, as compared with the original illumination when the installation was first made, is cut down by dirt to the extent of 10 per cent, without making any noticeable difference in the amount or quality of work done in that room, the question arises whether the cost to the consumer of cleanliness is anything like the proportional value of the lost light, as long as the depreciation in the illumination value of the lamps does not interfere with the work. The moment dirt begins to interfere with the work, and cuts down the volume of the work, so that the consumer cannot earn as much as he did before, his production is less in volume, and there is manifestly a rapid rise in the cost of the dirt from his standpoint.

E. B. Rowe: I do not know that I can answer specifically the question raised by Dr. Kennelly, but there is one point which might be brought up in connection with Mr. Clewell's paper, which he omitted, perhaps intentionally, and which I might point out in connection with the poor conditions under which the tests were made. These tests did not include any consideration of the effect of depreciation of the walls and ceilings, which are important factors in many cases. For example, in certain industrial installations, in light manufacturing spaces, it is customary to have light walls and ceilings which, by means of their diffused reflection, increase materially the total efficiency of the installation. The effect of dirt and dust depreciation of walls and ceilings may therefore be considerable. In one series of tests which were made under average city conditions this loss by decrease in reflection from ceiling and walls, which were originally white, amounted in the course of three months to from 10 to 14 per cent. These figures, of course, are only approximate and hold true only for the conditions under which the tests were made.

C. E. Clewell: In connection with Mr. Rowe's suggestion, I may say that practically all the installations tested were surrounded with very dark walls and the tests on the installation at the end of the run showed the illumination to be practically the same as at the start, so far as the surroundings are concerned. It would be very effective in the case of surroundings of light color.

Charles F. Scott: Referring to Dr. Kennelly's remarks, in illumination we have to do some things that are big steps. It becomes a concrete rather than an abstract theoretical science. To illustrate what I mean, I will refer to the computations which you make on long-distance transmission lines. You figure out the resistances to three or four distant places, and the efficiencies to several points, and then you take the nearest size of wire, which may take a 25 per cent jump. So in illumination, in considering a certain room we may say, if we can get along with 10 per cent less light, what is the need of cleaning lamps? Or, we might have put on, in the beginning, 10 per cent less of lamps, and got our necessary illumination, that is, might have secured a given amount of light from a few clean lamps, instead of from a greater number of dirty lamps. In a large hall where the lamps are inaccessible, it may be cheaper to let the lamps run somewhat dim and have more of them, than to have a man climb up to the ceiling every week or two and dust them off. The particular cost of the cleaning in the particular place, as well as the cost of power and the number of hours burning per day, are all factors, but to get a given amount of light, we can in many cases put in fewer lamps to begin with, and by keeping them clean can secure the maximum amount of illumination from those lamps.

Clayton H. Sharp: Referring to Mr. Clewell's paper, I think it contains a good deal of matter of value, and a considerable amount which is not entirely new. The efficiency values which he gives, the ratio of the lumens generated by the illuminant to the illumination effective upon a certain plane, have been worked out for a good many classes of installations before, but it is useful to have the additional data on this question which Mr. Clewell gives us in his paper, particularly since they refer to shop lighting. The deterioration values for the plant as a whole have also considerable novelty and a great deal of value. I think, however, we should very clearly bear in mind that the illumination of a shop is not a question of simply so and so many foot-candles upon a certain uniform plane, but that the illumination required is dependent to a very large degree upon the character of the work to be done, and particularly upon the reflecting power of the surface upon which the operator is working. The direction from which the major part of the rays of light comes, the diffusion of the light, the proper ratio of direct to general illumination, the protection of the eyes of the operators are also of very great importance in machine shop illumination. It follows that the problems involved in shop lighting can be solved only by a careful study of individual cases and of individual machines. No wholesale method, no general solution, such as producing three foot-candles of illumination on a plane 30 in. (76 cm.) from the floor, suffices at all as an answer to the questions involved in the proper illumination to enable operators to see and carry out their work as rapidly and conveniently, and with as little fatigue, as possible. From this point of view, the data which Mr. Clewell gives in showing the wages value of the lighting of the shop, the cost of lighting interpreted in wages value, are extremely interesting. They show how insignificant a factor the cost of the lighting really is, and how uneconomical it is to use anything less than the most full and most effective illumination. To curtail the amount of light used by operators is the worst possible kind of economy. At the same time it must be remembered that the word of the operative as to the amount of light he needs cannot be taken at its full face value. The amount of light which is really required is something which itself requires experimental study and careful measurement. The elimination of disturbing factors, such as glare and specular reflections, has a very strong influence on this, so that the judgment of the operative on the question needs to be supplemented by that of some one of more experience, the judgment of an illuminating engineer, who can determine these things with more certainty. It is clear, therefore, that the purely utilitarian illumination of a workshop is not a simple matter but a complex one, requiring the exercising of the best talents of the illuminating engineer.

Mr. Jones has shown us how carefully the decorative effects demanded in an entirely different class of illumination require to be studied, how the shadows and shades and the colors of the light have to be very carefully worked out, and that is very complex and requires experimental study.

It used to be said that illuminating engineering consisted in using tungsten lamps and holophane glassware. I think that what we have learned from these papers and demonstrations shows that there is a good deal more than that in the science and art of illuminating engineering.

F. C. Caldwell: There are two points that may be deduced from these two papers. The deterioration in the light due to the aging of the lamps, and especially to the lack of cleanliness, ought to be taken into account in the original design of the illumination. In many cases this is overlooked, and the illumination is designed on the basis of what the lights will give in their original condition.

Another point, which is very important in some cases, is the difference between illumination for use during the evening and for use during even a short period following daylight. It appears that in many cases a higher degree of illumination is really needed for a short period following daylight than for the whole evening, because the user of the illumination compares it with the daylight that he has been working with. The effect of the strain, on the eyes of a person who uses the artificial illumination for only a short time after daylight, may be quite severe, owing to the great change from the use of daylight to the use of artificial light.

G. H. Stickney: It is interesting to note that these two papers illustrate the scope of illuminating engineering problems, as well as different typical methods of solution. Mr. Jones has treated problems of the class in which the dominating consideration is artistic effect, while Mr. Clewell has selected installations where utility and cost are the prevailing factors. In the first case cost is a secondary consideration, while in the latter the esthetic appearance is of minor importance.

Again, in treating the problems, Mr. Jones has followed the laboratory method, while Mr. Clewell has adopted the practical installation method, or, as a lawyer would say, the "case system." Each has its advantages and limitations and is at its best when supplemented by the other.

The question of depreciation was mentioned by Dr. Kennelly. Depreciation is sometimes divided into two components, which have been designated as "inherent depreciation" and "acquired depreciation." "Inherent depreciation" is that due to the peculiarities of the lamp independent of its environment. It includes the internal coating of globes, decreased activity of illuminating materials, etc. All types of lamps are subject to inherent depreciation, but some types are more affected than others. "Acquired depreciation" is that due to the external conditions under which the lamp is operated. For example, the accumulation of dust and the darkening of ceilings and walls. "Acquired depreciation" is independent of the type of lamp, though it may be largely dependent on the character of the maintenance. Proper cleaning will keep it at a minimum.

This question of cleaning has been often discussed, but in spite of this it has not received the practical attention which it deserves. The illumination from an ordinary installation is either much poorer than it ought to be, or more expensive, due to lack of proper cleaning. Mr. Clewell shows how profitable cleaning is. Experience indicates that, in a large establishment, proper cleanliness can only be secured by organized cleaning at regular intervals.

Other points which have been brought out and which deserve particular emphasis are the low cost of operating a good lighting installation in proportion to the value of the illumination.

It is hard to understand why some plants still cling to an obsolete lighting equipment, when a modern installation requires but a small investment, as compared to the cost of a year's operation. Initiative in this direction is amply rewarded in improved illumination and often even a reduced annual cost of operation.

William J. Hammer: I wish to express my appreciation of the practical value of these two papers. One point I wish to bring up, which Mr. Scott has already referred to. It is a thing in regard to which every electrical engineer should take a firm stand—that is, the criminality of placing brilliant and bare incandescent lamps in positions where the eyes of operators and workers will be injured. I will cite one instance which recently came under my personal observation. I recently went into the offices of one of the leading scientific and engineering organizations in this country and noticed the stenographer writing at her typewriting machine with a powerful tungsten lamp throwing light directly into her eyes, and the light reflected from the white paper she was writing upon. I said, " Don't you feel a good deal of eye strain?" She said, " Yes, the writing gets so blurred at times that I cannot read it." I said, " You have a good deal of headache?" She answered, " I have headache all the time." I then remarked, " You have a good deal of dandruff?" She said, " Yes, it bothers me a great deal." I said, " If that light is not changed you will lose your hair as well as your eyesight." I took a string and tied the lamp back so that the light came over her shoulder and was kept away from her face, and I think it is still hanging in the position in which I tied it, at least it was when I went in there the last time. A good many people who knew about the bad effects of such an exposure of the eyes to a strong light went into that office and saw that lamp hanging there before I did. Many of us now walk along the street and see powerful tungsten and other lights blinding the people passing the store windows and in the homes, offices and shops the people are not only destroying their sight but their hair. We should take that matter up and use our influence in having that corrected by the proper placing of the lamps, and the use of proper shades and diffuses.

One other thing occurred to me during the discussion, the importance of taking care of the deposits on the reflecting surfaces, besides the surfaces of the mere shade itself. A prominent efficiency engineer told me that he had succeeded in getting the cleaning of windows in a factory down to four motions, and hoped to get it down to three motions. We all realize, though we do not bother our heads much about it, the need of keeping windows clean so as to let in the daylight. If we are efficient engineers in regard to illuminating problems, let us take care of that factor also, and see that all reflecting surfaces are kept clean and in the best possible condition. I asked the same efficiency expert if it was not better at times to replace the glass windows instead of attempting to clean them. He replied that this was frequently the case.

E. A. Champlin: Reference has been made to lighting drafting rooms and also the manner of interior lighting through windows in the daytime, and I would like to ask if any particular effort is made to use the same direction of illumination with artificial illumination as you get through the window? In the drafting room the tables will always be so arranged that the lighting is most effective and in the proper direction for the use of a draftsman during the daytime. The window lighting will give him light so directed that the shadows will not interfere with his work, but I have noticed in most drafting rooms that the artificial lighting is not so placed, but is often placed so that it directly reverses that condition, so that the draftsman has to work on the other side of his triangle, and perhaps even of his T square. I wonder whether there is any effective means of duplicating the direction of lighting from the windows when artificial lighting has to be resorted to. Of course, if we do not get the direction right the draftsman will " plug in " somewhere and use a portable light, much to the detriment of his eyes, as has been pointed out by Mr. Hammer in the case of the stenographer.

C. E. Clewell: Answering the question of Mr. Champlin, I may say that very often the artificial light can be made to exceed in its advantages the direction of daylight; that is mainly brought about by the use of so-called semi-indirect lighting, which has been used in a great many cases under my own observation, and produces results which really exceed the advantages of daylight. The directional features in the semi-indirect lighting are such that the shadows are not reversed from what they are in the daylight.

Dr. Sharp called my attention to the possibility that my paper may have given the idea that the refinements or problems of industrial lighting were very simple compared to the decorative features which had to be considered in such problems as have been described by Mr. Jones. I did not wish to give the impression, by the various items which are set forth in my paper, that the problems in industrial work are not complex. For example, in one large installation it was found necessary to make a study extending over several months, in order to get the directional features of the light properly proportioned and placed with respect to the individual class of work. It was found, for example, after making a study of the needs of the installation, that merely distributing the light uniformly over the work, with a uniform capacity of the light, to a certain point on the average, would not at all solve the problem in this case, and it was necessary to raise and lower the lamps, and try different classes of fixtures so as to increase the light on a vise, for example, and for different classes of very fine work.

Another interesting problem has been the feeling on the part of workmen that individual lamps must be used in connection with some classes of work. In one installation, where three 100-watt tungsten lamps were installed on the eighth floor, and in which, prior to the installation of the new system, a good many hundreds of incandescent lamps were used, the superintendent, foremen and workmen themselves said that the individual lamp could not be dispensed with. We requested the foremen of the various floors to permit us to remove the individual lamps for a period of one month, during which time the workmen should try to perform their duties by the use of the overhead light, with the understanding that if it was not satisfactory we would put back all the individual lamps called for. We removed something like 1200 individual lamps, and after the month was over we were called on to put back merely two or three dozen on a floor space of 250,000 sq. ft. (23,225 sq. m.). This shows that the notions of the workmen, or even the superintendents themselves, cannot always be relied on in the matter of the light that is required.

The idea that I wish to emphasize in closing is that the problems are exceedingly complicated, even in those cases which seem most simple, for example, in industrial work, where the matters of reducing shadow effects and producing certain color effects are most important, in interior work, and you will therefore see that there are many difficult and important problems in connection with the proper lighting of industrial plants.

Charles F. Scott: A man in the mechanical engineering profession, Mr. Hunt, said to me something I want to say to the illuminating engineers particularly. He had a drafting room and a factory, and had tried different kinds of light. He said, " The great thing now is that we can lay out our factory and drafting room without reference to windows, considering only the efficiency of the machines and the progress of the work, and we can get our light from artificial illumination, which is better than daylight."

M. Luckiesh (communicated after adjournment): In reply to Mr. Champlin's question I would like to present my experience in attempting to imitate daylight distribution in an interior by the use of artificial light. A room with three windows—two on one side and one on the other—was fitted with removable dummy windows made of white diffusing cardboard. These dummy windows were placed in the window openings and illuminated by means of a special reflector hung on a bracket about 2 ft. (61 cm.) from the wall and near the top of the window. These reflectors were so adjusted that about the same relative distribution of brightness on the windows was obtained by artificial light as that presented to the view under daylight conditions. The distribution of light in the room was quite like that prevailing under the natural lighting conditions. The effect was pleasing. No measurements of the percentage of total lumens effective on a horizontal plane were made, but an idea of the possible " efficiency " of the installation is gained from such measurements on daylight in the same room. It was found that 33 per cent of the total lumens of natural light which entered the room was incident on a horizontal plane 36 in. (91 cm.) from the floor.

This shows that the "efficiency" in a room with light walls and ceiling need not be prohibitively low with this kind of an installation. I believe, however, that in many cases artificial lighting can be made far superior to natural lighting. Certainly special cases will arise where such a scheme will be useful.

Some experience with this trial installation gives some information relating to the point which Mr. Caldwell brought forth, namely, that more artificial light is needed just as daylight fails than later in the evening. This of course depends entirely on conditions. If daylight fails gradually and the lights are switched on at the proper time the eye will have become adapted to its new condition and no change will be noted. From a practical standpoint the eye becomes adapted to a change in illumination in a very short time. The installation just described permitted the closing of the dummy windows in a few seconds, thus changing from natural lighting of about 50 foot-candles on the test plane to artificial lighting of about 2 foot-candles. No more than a minute or two was required to become quite adapted to this abrupt change.

Roscoe Scott (communicated after adjournment): After reading Mr. Clewell's instructive paper, I am convinced that the test data he gives should be a valuable addition to the notebook of any illuminating engineer, especially of those who have to deal with the lighting problems of shops and mills, including the maintenance of lighting equipment. I wish to confine my discussion, however, to that section of the paper, near its close, entitled "Economic Relations."

The three charts comprising Fig. 16 bring out in a very forceful manner the pettiness of the illumination cost as compared with the cost for labor in the average industrial plant. One conclusion must certainly be drawn from these charts, namely, that a very considerable percentage increase in lighting expense may be justified if it will produce an increase—even a small increase—in the efficiency of labor. Some time ago I worked out sets of curves intended to show graphically the general relations between the several variables which must be considered in estimating that increase in lighting expense which will result in the maximum net saving for an industrial concern.* One of these charts may be worth reproducing in this connection. On it the net saving is plotted (see figure) as ordinates against increase in lighting expense as abscissas. As this is intended to be a general graphical solution of the problem, the variables are necessarily expressed as percentages rather than in absolute measure.

The increase in labor efficiency (*a* on the chart) should be understood as being measured by the resulting decrease in cost or the profitable improvement in quality of the manufactured product; it may or may not be directly measurable in terms of the increase in individual production.

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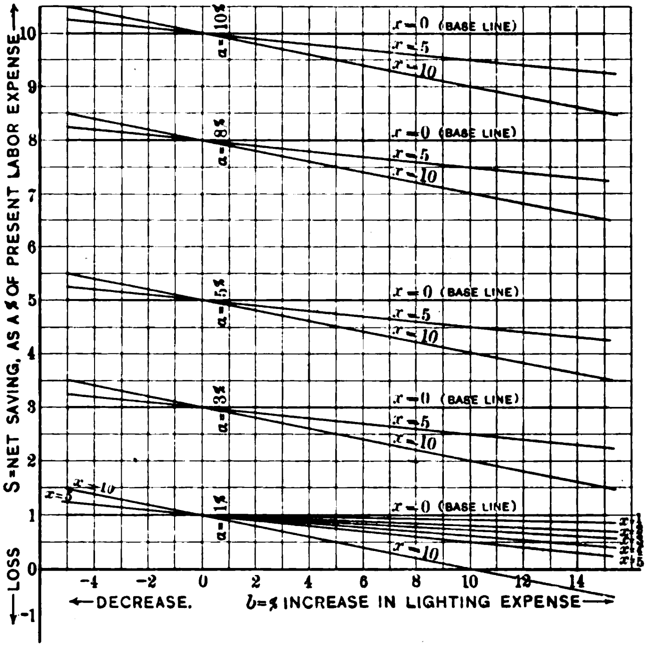
*See *Electrical World*, Feb. 10, 1912, pp. 317-319.

The chart really consists of several distinct sets of curves, one set for each value of *a* (the expected per cent increase in labor efficiency). In using the chart one picks out the particular bundle of curves labelled to correspond with the assumed value of *a* and then follows up the line corresponding to the given value of *x* (for definition of this symbol see chart), on which line the saving corresponding to the assumed increase or decrease in lighting expense may be found as an ordinate. As a numerical example:



Definitions: x = Ratio of lighting to labor expense (percentage)
a = Increase expected in labor efficiency (percentage)

$$S = a - \frac{b\,x}{100}$$

Ten compositors employed on a night shift in a large print shop receive an average wage of $25 a week. The present lighting system costs $1.75 per week.

Then $$x = \frac{1.75}{250} = 0.7 \text{ per cent.}$$

The manager estimates that the improvements in the illumination system necessary to produce a 1 per cent increase in efficiency of the men will increase his operating expenses for lighting by, say, 15 per cent. Referring on the chart to the bundle of lines marked "$a = 1$" we find by interpolation the point where a line corresponding to $x = 0.7$ would cross coordinate $b = 15$. This point is seen to correspond with a value of S, the saving, of 0.9 per cent. That is, the net weekly saving expected is 0.9 per cent of $250 = $2.25. By trying different values for b, with the corresponding estimated values for a, a condition which will give the maximum net saving (" on paper ") may be found.

Of course, the value of a—by far the most important factor in the calculations—must be estimated from the proposed changes in the illumination, rather than directly from the increase or decrease in operating cost consequent upon such changes. The difficulty of estimating it is enhanced because so many factors, such as diffusion, direction and color, as well as intensity of light, must be taken into account in deciding the comparative value of two or more industrial lighting installations from the labor-efficiency standpoint.

We must rather ruefully admit that the illuminating engineer who has amassed any considerable amount of data of value to a practical man in determining a for his particular case, be it the lighting of a silk mill, a clerical office or what not, is the exception rather than the rule. Such data—into which the human element enters so largely—must invariably be based on experience or special test, and are particularly hard to obtain. If those who have reliable figures would place them—in addition to the purely physical data that Mr. Clewell has presented—before the members of the national technical societies they would be of untold benefit in the future application of industrial lighting economics.

Bassett Jones, Jr.: Mr. Moore brought up the question of the diffusion of daylight. We have heard a great deal in the last few years of the necessity of copying daylight in interior illumination, both as to color and diffusion. My own personal opinion is that rarely can the problems of interior illumination be solved by any attempts to copy daylight. The differences between all sources of artificial light and the sources of daylight are to great to permit any true similarity in their effects. Having read Mr. Luckiesh's communicated discussion I should like to add that I entirely agree with his statement that daylight can even be improved upon by artificial means. I tried to draw attention to the fallacy of the superiority of daylight some time ago in a discussion of a paper by Prof. Nichols presented before the Illuminating Engineering Society, but at that time daylight and efficiency were the pass words of the art, and my attempt was quite bare of results. As far as the diffusion of daylight is concerned, the relation of directed daylight to diffused daylight can be very readily discovered by so holding a piece of white cardboard that one side is exposed to direct rays from the sun and looking at the other side. The difference in intensity between the two sides of that sheet of paper will be enormous. In other words, a large proportion of daylight is directed light. The moment we have an overcast sky, so that the light is thoroughly diffused, we have trouble in seeing, and particularly if the sky is not very dense. There is under such conditions a decided tendency to shade one's eyes. Perfect diffusion is not good for the eye, because the eye is not given a chance to perform its proper function.

Of course, in interiors it would be ridiculous to attempt to reproduce the intensity of daylight. In the first place, if we are going to do work in the open daylight, work which requires close application of the eysight, we want to be shaded from the daylight. If you are reading a book in the daylight, you usually seek a shaded place in which to read, or if there is no shaded place you will open your umbrella and read the book under the umbrella. Consequently, for artificial interior illumination, the solution of the problem cannot be determined wholly from the conditions of daylight illumination.

Mr. Moore asked whether the effects obtained in my demonstration were secured by the use of colored screens. They were. He also suggested the use of the different artificial illuminants, each for its own color value. This has been done in the case of the Soldiers' Memorial in Pittsburgh, where incandescent lamps were used for their color value, the Moore tube for its color value, and the mercury-vapor lamp for its color value, and the color values of the different illuminants play a very large part in the general color scheme of the design. The green light from the mercury-vapor lamp, slightly modified by a particular form of opal glass produces a moonlight effect, which has become a part of the color scheme in the ceiling. So with the light from the Moore tubes. The flame arc serve to produce sparkling centers of an orange hue. The efficiency of course, is low, because the lamps are not used to give light on the floor, but simply to give an effect of a jewel-studded ceiling.

In regard to the color of daylight, I performed some simple experiments a short time ago for the benefit of an architect, with reference to the problem of the color in which rooms should be painted. The average architect, like the average decorator, still believes that red, yellow and blue are the primary colors, and also that a north room should be painted yellow and a south room should be painted blue.

The experiments were carried on in a building in which there is a long corridor, on the south side of which is a series of offices with windows opening to the south. On the north side of the corridor is a series of offices with windows opening to the north. That light from the north sky is decidedly blue, and the light from the south sky decidedly yellow, was shown by giving the architect a little piece of cardboard, which he held before his eyes, so as to cover the window. The moment he covered the window with the piece of cardboard, that is the moment he covered his eye with the cardboard so that he could not see the window, he was asked to state the color of the unpainted plaster walls. In the north room he said blue. In the south room he said they were light buff. Therefore, the proposition was put to him that the north room should be painted blue, in order that the blue light should be reflected from a blue surface. If it was painted buff, it would absorb and not reflect blue light. The south room should be painted buff, because the buff walls would reflect the yellow light better than if the walls were painted blue, which would absorb the yellow light.

The result of this and other experiments was that the north rooms were painted a light blue and the south rooms were painted a light buff, and then came the question of artificial light. We were going to use tungsten lamps with reflectors, but we did not want to make the north rooms blue at night, and we had to mix with the blue a little green which would respond to the tungsten light at night. The yellow walls in the south rooms did respond to the artificial light without any modification.

These experiments give a practical example of how far the question of illuminating engineering can be carried. In fact, by such methods the best balance of color values for wall decorations can be determined in many interiors with a resulting heightening of the effects. Thus it is possible to determine for a given southern interior that the general color tone should be, say a buff corresponding nearly to number *x* in any given scale of pigment hues, and that on top of that color another color must be applied, say about 50 per cent of the wall area, must be painted quite red laid on in any design the architect may desire. A room painted that way, with consideration of the daylight sources, will give a very much more heightened effect and will incidentally prove more efficient from the standpoint of illumination than if a decorator painted it as he saw fit. Now, while this is true, tell it to almost any architect and see what he will say.

Mr. Millar said he thought it would have been interesting if the numerical results of the experiments had been given. The trouble with these experiments is that they have to be taken with a very large grain of salt; that is, it is impossible to conduct such a study, and apply the results promiscuously.

DISCUSSION ON "POWER REQUIREMENTS OF ROLLING MILLS" (SYKES), AND "THE ECONOMICAL SPEED CONTROL OF ALTERNATING-CURRENT MOTORS DRIVING ROLLING MILLS" (MEYER AND SYKES), NEW YORK, NOVEMBER 8, 1912. (SEE PROCEEDINGS FOR NOVEMBER AND DECEMBER, 1912.)

(Subject to final revision for the Transactions)

John M. Hipple: The general tendency in industrial engineering is towards refinement in methods and apparatus. Only an exact knowledge of those requirements enables us to meet them successfully. The steel industry is a notable example of this condition. The making of steel requires high-power substantial machinery, the first demand on the machinery being continuity of service.

When the application of electricity to steel mills was first taken up, the first motor that was available which the steel mill engineer thought by any chance would do the work, was put in service. If it broke down, a larger one was put in service, and this was continued, until a motor was secured which would stand up to the service. The same was true of control apparatus. The tendency was for many years, after reaching that point, to duplicate that application, unless the new application required more power, in which case a larger motor was used. More experience and more exacting requirements have indicated the necessity for investigations such as the one which has been undertaken and reported upon in Mr. Sykes' paper.

Such investigations are sure to advance the cause of industrial electrical engineering, and, further, to increase the economy of production, and these are the things that the members of the Institute who are interested in industrial engineering are particularly anxious to see forwarded.

J. H. Wilson: In looking over this paper by Mr. Sykes, I feel that considerable credit is due the author for the clear and comprehensive manner in which he has subdivided and explained the various elements entering into the determination of the amount of power required to roll steel in its various forms and shapes. Concerning this part of the paper there is not much to be added of a general nature. The only thing that might be added would be more complete data concerning some actual installations.

Referring to the paragraph under the heading "Practical Determination of Motor Size," in this paragraph Mr. Sykes fails to bring out clearly the fact that the utilization of flywheel energy is more or less of a necessary evil. The use of a flywheel is made necessary in most cases, by considerations external to the motor equipment, such as the supply of electrical energy or the arrangement of the mill drive. For example, a sheet mill with rope drive between the motor and mill must necessarily have flywheel effect on the mill side of the ropes, as the power required for rolling varies so greatly that with the flywheel on the motor side the ropes would jump, run unevenly and be subjected to such variations in pull as to materially increase the maintenance cost. The necessary flywheel effect is usually obtained from the large rope sheave wheel.

The following facts should be noted:

First.—In order to obtain energy from a flywheel we must permit the slowing down of the equipment. This means the adding of external resistance to the rotor of the induction motor, which in turn results in decreasing the efficiency of the motor at heavy loads where efficiency is most important from a power consumption point of view.

Second.—The slowing down of the flywheel in turn slows down the rolls and decreases the amount of material which can pass through them in a given time.

Third.—Additional power is required due to the friction load caused by the flywheel. This power becomes of considerable importance, as it mus tbe expended all the time, when the mill is running idle as well as when rolling steel.

Fourth.—The use of a flywheel adds expense, due to the necessity of maintaining large heavy bearings, keeping them properly lubricated and in good mechanical condition.

The load diagram, Fig. 11 of this paper, is fairly ideal for the use of flywheel equipment. The passes are of short duration and the interval between passes is sufficiently long to allow the motor to re-accelerate the flywheel from a very low speed to nearly synchronism.

In an installation such as this the additional first cost of a larger motor would probably offset the savings which would result from the elimination of the items shown above as being objectionable in the case of flywheels. In case, however, we consider a load curve in which the average load is, say, twice the average load shown in this curve and the peaks remain the same as shown on this curve, the flywheel would probably not be warranted, this heavier average load being assumed to have resulted from a decrease in the interval between passes.

The above argument is based entirely on a consideration of the power conditions at the mill. If, however, other conditions, such as power station capacity and arrangement of the mill drive, are allowed to enter into this matter the question assumes an altogether different aspect. Assuming that the power supply for a rolling mill is of sufficient size so that the maximum fluctuation obtainable from one driving motor or the accumulated fluctuation from a number of driving motors is small as compared to the total station load, then these questions of economies in operation are of first importance. In other words, these economies might well be sufficient to cover the increase of a motor size as much as 50 per cent, which increase would not affect the efficiency at light load but would greatly benefit from the elimination of flywheel expenses. On the other hand, if the power station is comparatively small and an individual motor is large in comparison to the total average load, then flywheels and automatic regulators are necessary, as the economies referred to could not possibly offset the additional cost due to the operation of the power station under the extreme variations of load which would be met with. These economies could not, of course, offset additional cost which would result from the operation of power station machinery below its normal capacity, as the efficiency of the generators and driving units would be of considerable importance.

The equipment of individual mills determines the power station load curve and the flywheel is more often made necessary on account of the fluctuation here than on account of the power requirements of the individual mill.

The electrolytic regulator referred to by Mr. Sykes makes the use of flywheels more economical than does any other type of induction motor regulator with which I am familiar. This regulator permits the operation of the motor and flywheel at the highest possible average speed and will cause the motor to re-accelerate the flywheel much more quickly than will any resistance stepping device on the market.

This question of motor and flywheel sizes is one which presents different phases in each installation and necessarily must be figured to meet local conditions.

Selby Haar: All engineers who are called upon to become familiar with the power requirements of rolling mills will owe their thanks to Mr. Sykes, because he has collected facts which heretofore have been scattered in a great many places. As long as the known laws of the subject are largely empirical, the collection of data for generalization will be restricted to the few who are able to conduct the very expensive and extraordinarily difficult tests. As an instance of the meagerness of our knowledge, it may be pointed out that practically all the available data relate to iron and steel.

Mechanical engineers interested in roll driving contented themselves generally with measuring the fuel and water consumption of the engines, so that the electrical engineer entering the field was compelled to exercise imagination as well as judgment in recommending motors. Even in the present state of our knowledge, it is still advisable to make a minute study of local conditions before recommending a motor equipment, because the steady operation of the motor frequently increases the output of a mill beyond all expectation; and an electric motor does not, like a steam engine, deliver its maximum capacity continuously without injurious heating. As soon as electric motors began to displace steam engines, however, precise testing began; a German manufacturing firm collected a complete set of measuring instruments for this purpose alone, with which a committee of the Society of German Foundrymen (Verein deutscher Eisenhuettenleute) conducted the extensive series of tests which is the nucleus of the published data.

It was fortunate for the testing engineer that reversing mills were among the first to be electrified, because direct-current motors were used, which simplified the design of graphic meters. Even with the present refined testing apparatus, however, it is not clear why there should be such a difference in the nature of the results obtained by different experienced engineers, such as, for example, results published in *Stahl und Eisen*, June 9, 1909, and *Iron Age*, January 4, 1912. Both sets of tests show a fluctuating torque for a constant reduction of the thickness of a piece during a pass, which is contrary to the usual assumption.

In the construction of load diagrams for mill cycles, I have found it easier to deal with the elongation of the piece rather than the actual volume of metal displaced as has been done by Mr. Sykes in Table I of his paper, because this method lends itself readily to wide changes in ingot or billet sizes, and also fits in well with the working range of the slide rule.

In regard to the automatic regulation of resistance mentioned on page 2030, it should not be overlooked that a regulator which can perform its function during passes, the duration of which is a few tenths of a second, must be exceedingly rapid.

In conclusion, however, I wish to express my thanks to Mr. Sykes for the preparation of this paper, which must have entailed a large amount of work; and it is to be hoped that it will stimulate the publishing of more data on this important subject.

Edward J. Cheney: With the application of electric motors to main roll trains there has arisen the necessity of determining with as much accuracy as possible the power requirements for rolling steel. With engine drives the size of the engine was rarely, if ever, calculated, but was determined almost solely from judgment and experience. If it was known that a certain mill was running satisfactorily with a certain size of engine, and a similar mill was to be installed, the same size engine would probably be used, or, perhaps, a trifle larger for safety. The result of these methods is that most rolling mill engines are too large and very few are of the proper size. It is not an uncommon sight to see engines running which take steam for only one or two strokes at occasional intervals.

Mistakes in engine size are not attended with serious results except as regards efficiency and possible handicaps on production. If the engine is too small the mill stalls. The rollers then judge that the capacity of the mill has been reached and ease up on the work. Most engines have heavy flywheels which will carry them over the peak loads and, with steam driven mills, speed variations are tolerated which would not be considered with motor drive.

In determining the size of motors, such haphazard methods are not, or should not be, used. If the motor is too large a low power factor results, to say nothing of lower efficiency and increased first cost. It should be noted that the latter items apply equally well to engines, but are not so much considered in their case because the error in capacity is not so easily noticed.

If the motor is too small the mill will not stop and so compel mercy from the rollers, but the over-willing motor will continue to turn the rolls until it overheats, and perhaps burns out and is cursed for being inadequate.

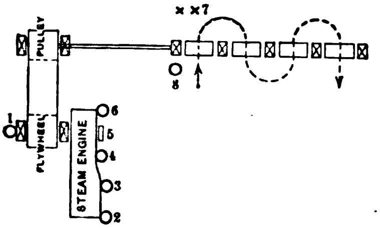
This quality of the electric motor, which causes it to take enormous overloads without any appreciable change in speed, has resulted in a large increase in production in nearly every instance where mills have been changed over from steam to electric drive, merely because the rollers are then enabled to crowd the material through, absolutely regardless of the driving motor. For this reason engine tests must always be used with caution as a basis for determining motor sizes.

The electrical engineer must have at hand all of the information possible and needs much more than is now available. Mr. Sykes has well pointed out the difficulties which are encountered in this work, probably the greatest one of which is the ignorance of what any mill will ultimately be called upon to do. Considerable progress has been made in determining the power actually required for rolling under various conditions, and, particularly in the case of mills used simply for reductions in section without much distortion of shape, fairly reliable data are available. This includes blooming, billet, slabbing, and plate mills, and mills for rolling simple shapes, such as rods and bars. It is on merchant mills that the greatest uncertainty exists. Here a great part of the work is used not in elongating the piece, but for distorting its shape, or is consumed in friction, as shown by the author. For such mills there is no reliable information except from actual tests under the exact conditions. This is a laborious task but apparently a necessary one. Much has already been done, enough to afford approximately correct information for most conditions, but much more remains to be done before complete data are obtained for all cases.

While not strictly pertaining to this subject, it may be remarked in this connection that the ease with which power is measured in the case of electrically driven mills is really one of the greatest advantages which they possess. This fact not only makes possible the accurate determination of power for future installations, but is a constant check and guide to rolling methods in the mills already equipped. With engine drive little attention is paid to the setting of valves or the condition of the rolls, because there is no direct way of determining the power consumption. But with electric drive the indicating wattmeter faithfully points out and the watt-hour meter relentlessly records the power input to the motor, and the influence of various factors is readily seen. The mill superintendent soon learns to watch the meter. He knows what has been the record for any section and any increase in power over that record causes an immediate investigation to determine the cause. This stimulates activity in searching for further possibilities of reduction. Instances have been known where over 25 per cent saving in power has been accomplished by slight modifications in roll shapes without in any way affecting the quality of the product.

Bayse N. Westcott: I was very much interested in Mr. Sykes' paper, because I have encountered the same troubles in testing that he has. Mr. Sykes mentioned the difficulties in getting accurate speed measurements on mills. With an induction motor of the slip ring type, you can get very accurate speed measurements, because the slip of the motor with a given resistance in the secondary is, within reasonable limits, inversely proportional to the input, so that if you know the characteristics of the motor, or if you can make an experimental determination, all that is necessary is to record the input with a sufficiently sensitive curve-drawing wattmeter and you can determine the speed of the motor at any instant from the record of kilowatts input.

Mr. Sykes did not say anything about steam engine driven mills. They are the most difficult mills to test and also very important, because it is the present steam driven mills which are largely being electrified and which mean business to the electrical manufacturer.



1—Liquid tachometer and contact maker.
2 and 3—Continuous steam-engine indicators.
4—Reducing motion
5—Stroke counter.
6—Recording instrument
7—Mill observers.
8—Electric gong.

Fig. 1

In steam driven mills, one of the first essentials is to secure a good record of the horse power developed by the driving engine while the steel is being rolled, and the best way to do this is to use a continuous drum steam engine indicator. This differs from the ordinary steam engine indicator in that the paper on which the indicator card is made is a long strip, which is reeled inside the drum and feeds around the drum a quarter of an inch (6.35 mm.) at each stroke of the engine. Fig. 1 shows the general layout used in testing steam driven mills.

Fig. 2 shows details of recording instruments for speed, time and general information regarding work in the mill. These have pens actuated by magnets, which mark on a strip of paper which is moved at a uniform rate beneath the pens by a spring motor. In most cases three pens are used, marked *A*, *B* and *C* in the figure. *A* is actuated by a contact maker, which is driven from the engine shaft or other convenient place so as to complete the circuit of magnet *A* several times for each revolution of the engine. The number of contacts per revolution depends on whether the engine is of high or low speed. Pen *B* is controlled by a contact-making clock, which is regulated to close the circuit of *B* once in every five seconds, or at shorter intervals if preferred. In addition to actuating *B*, the contact-making clock also closes the circuit of an electric bell, or in some cases, that of an electrically operated whistle. The third pen *C* is controlled by a manually operated key located at the rolls.

In addition to the foregoing, a liquid tachometer, consisting of a small centrifugal pump which raises a column of colored alcohol to a height depending on the speed at which the pump is driven, is used to indicate speed variations of the engine. A stroke counter is connected to the engine to record strokes and furnish a check on the graphic instrument.

The equipment described will secure an accurate record of the power that is furnished the mill.

Speaking of graphic meters, Mr. Sykes said that in using the

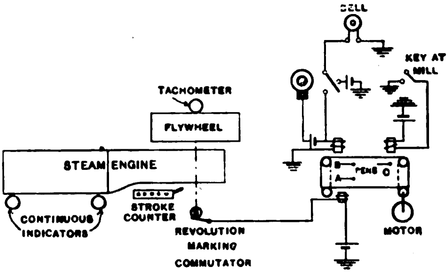


Fig. 2

graphic meter the pen should not touch the paper. We used successfully a high-speed graphic meter, with a pen which used ink, and which did rest on the paper. We used a paper speed of about 30 in. (76 cm.) per min., which is only half the speed used by Mr. Sykes, which was one in. per sec., or 60 in. (152 cm.) per min. I suppose the paper in the tests referred to by Mr. Sykes was driven by an electric motor. On our graphic meters we had spring motors, which, of course, are not as good as an electric motor drive for the paper.

The chief thing about instruments for use in steel mill testing, especially in commercial testing, is that they must be reliable. They must be hardy, as they have to be shipped around the country by express to various mills and they are liable to rough treatment.

David M. Petty: I would ask Mr. Sykes if he has any figures which show the relative kilowatt-hours necessary, for a given reduction, with a fast or slow rate of displacement. I refer to the paragraph in his paper headed "Rate of Displacement."

Fred Bickford Crosby: Messrs. Meyer and Sykes have presented for our consideration a problem of especial interest to every engineer concerned with the application of mechanical power. In the manufacture of steel the introduction of the direct-current motor brought about revolutionary changes in established methods. With the advent of the polyphase induction motor the superior advantages of alternating current were quickly seized upon, particularly where power in large quantities must be distributed over a considerable area. Today, even for the largest drives where only a single constant speed is required, the high efficiency and substantial simplicity of the induction motor leaves it practically without a competitor in new installations. With all its good qualities, however, the induction motor for certain classes of service possesses two undesirable characteristics —power factor and inability to secure adjustable speed regulation.

Multispeed induction motors with changeable pole connection to give a 2 : 1 speed ratio or with separate independent windings to give some third speed, have in many instances proved a satisfactory compromise for adjustable speed control. The efficiency of such a machine may be fairly high for each of the several synchronous speeds, but the power factor is invariably poor at the lower speeds. With rheostatic control the power factor is reasonably high at all speeds, but, since with constant h.p. output the slip energy dissipated is directly proportional to the reduction in speed, the low efficiency encountered renders continuous operation at reduced speeds prohibitive. Furthermore, the induction motor with rheostatic control has an unfortunate tendency to accelerate automatically as the load falls off. Direct or differential concatenation of two single motors or of a multiple-wound induction motor has been employed to secure as many as six independent synchronous speeds for a single set, but only at a heavy sacrifice in simplicity and other desirable features.

Until recently it has been practically necessary to resort to direct-current motors to obtain strictly adjustable speeds, that is, several independent speeds, each constant under variable loads.

Recently there has been a steadily increasing demand for an adjustable speed alternating-current motor. In recognition of this demand the company with which the writer is connected has for nearly two years been carrying on a series of very thorough investigations, both theoretical and experimental, to determine which of the numerous schemes suggested for obtaining shunt speed characteristics is commercially feasible. The company is now prepared to furnish speed regulating sets for use with standard phase wound induction motors. The form which these sets will take depends very largely upon the requirements of the installation in question. Of all the schemes suggested two have successfully withstood the test of actual installation. Either of these methods will give a uniformly high efficiency and, if desired, unity power factor throughout the speed range for which the set is designed. In general, power factor correction above 95 per cent is not recommended, since the higher percentage correction is obtained at an expense wholly disproportionate to the benefits resulting.

The first of the two methods advocated employs a compensated commutator motor which transforms the slip energy of the main motor into mechanical energy and drives a high-speed induction motor connected to the supply main, slightly above synchronism, thus causing it to operate as an induction generator and return electrical energy to the system. This scheme has proved especially satisfactory for 25-cycle systems and speed regulation not exceeding 30 to 40 per cent. These sets are also practicable for 60-cycle service, provided the regulation required is not too great.

For regulation in excess of 50 per cent where the slip frequency is high and the output large the second method is usually preferable. In this case a special synchronous converter is used which transforms the slip energy to direct current. This in turn is used to drive either a high-speed d-c.—a-c. motor-generator set for returning energy to the system electrically, or to drive an adjustable speed d-c. motor mounted on a shaft extension of the main motor.

It should be distinctly understood, however, that these sets are not a universal panacea for chronic speed difficulties. Each is subject to limitations, but of all the various schemes proposed the two which I have mentioned appear to be by far the most satisfactory from the viewpoints of practical design and economic operation. Some of the other schemes appear more simple in diagram, but I believe will be found to involve serious difficulties both in electrical and mechanical design, particularly in those cases where it is proposed to pass the entire slip energy through the regulating transformer.

In spite of the very real advantages which these regulating sets possess for the various classes of service mentioned, there are still occasions when sound engineering will warrant only the use of direct-current motors to meet the requirements of adjustable speeds.

I recently had occasion to investigate the comparative characteristics of a 350-h.p. mine fan motor with rheostatic control and with commutator motor regulating set arranged to give 20 per cent speed reduction, with the following interesting results:

Per cent regulation	Regulating set		Rheostatic control	
	Efficiency	Power factor	Efficiency	Power factor
0.5	88	100	84	91
10	87	100	82	91
15	86	100	77	91
20	84.5	100	72.5	91
25	84.5	100	68	91

On the basis of 0.6 cent per kw-hr. the saving per annum effected by the higher efficiency of the regulating set would be approximately **$2700.**

Another interesting case involving a 6500-h.p. motor with the synchronous converter and motor-generator designed for 40 per cent speed regulation gave the following results:

Rev. per min.	Over-all efficiency	
Main motor	Regulating set	Rheostatic control
85.6	87.0	73.5
75.0	83.7	64.0
64.3	80.0	55.0
53.5	75.0	46.0

The arguments of complex control often used against the speed regulating set lose much of their weight in view of the present excellence of automatic magnetic control and the increasing tendency among steel mill engineers to place the motor with all accessory control in a room separate from the mill.

L. T. Robinson: I wish to make one general remark, and to refer specifically to one point in Mr. Sykes' paper. The general remark is that I think we have been much benefited by the discussion of methods of measurement, together with the general subjects to which they are related. There is very seldom an engineering problem that does not involve some problem of measurement, and to get the most good out of the whole thing it is well to take them up together, as they have been in this discussion.

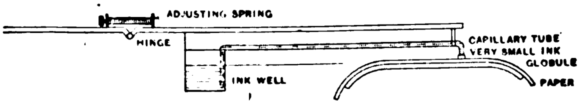


Fig. 3

The specific point I wish to raise is in connection with the spark method of recording. I was much interested in the reference to that method—it brings out the fact that one thing, although it may be good, is not always useful to cover every condition that comes up. The advantages of this spark method of recording are quite obvious, but, in my experience, it has some disadvantages.

The paper which is used for the record is somewhat irregular in thickness, and in getting a difference of potential between plate and pointer that will strike through in a satisfactory manner, you encounter two troubles—first, if you use a high potential that will strike through rather definitely, you are likely to run into trouble with electrostatic effect between the pointer and the frame of the instrument; second, sometimes there is a tendency to puncture at a point not directly underneath the needle, especially if a comparatively low difference of potential is used. This means that you must develop a considerable difference of potential, and guard successfully against the electrostatic effects by using a considerable torque, to get the same degree of precision that you can get in other ways.

I will show what means have been employed in the instruments that have been referred to by some of the previous speakers, to overcome the effect of friction on the paper, etc. (See Fig. 3.) Friction is minimized by an arrangement to feed the ink by capillary action, leakage on to the paper being prevented by surface tension at the recording point. The arrangement will not leak, and the ink will flow freely, and it can be adjusted to the paper so that it is in very light contact, and after the pen starts, it is simply the contact of the ink and paper and not of the pen point.

H. L. Barnholdt (by letter): When determining the motor size during the early stages of introducing electric rolling mill drives, the tendency was to follow the steam engine practise in many cases, *i.e.*, to use a motor large enough so that the first thing to break would be some part of the mill rather than the motor. This, no doubt, was good practise with the meager data then on hand in regard to the power requirements, as it would have been poor policy to run much risk of the motor breaking down when endeavoring to introduce the electric drive. Although at the present time the economy of electric rolling mill drives in general, as compared with steam drives, has been fully established, competition has made the question of further increasing the economy of these drives one of great importance. Not only can the initial investment be made low by selecting a motor of proper capacity to handle the requirements, but the performance of such a motor will be superior to that of a larger motor running underloaded. The ease and accuracy with which the electric power consumption of these fluctuating loads can be determined, as compared with steam, has done much to bring the subject of rolling mill practise to a more scientific basis. It also enables the motor manufacturer to work closer on the design and still be within limits of safety.

G. E. Stoltz (by letter): Mr. Sykes has mentioned the difficulty in obtaining the tonnage output of a mill from the operators. It seems to me that by knowing the peripheral speed at which the metal is rolled and the method of handling the material, an engineer who is acquainted with this phase of steel mill work should be able to estimate very closely the output which the mill is capable of rolling.

It has been stated that it is the practise of some engine builders to supply an engine large enough to break some part of the mill. This seems to be rather an expensive method of playing safe. Of course, in the absence of the necessary data to make an intelligent calculation of the power required, it is easy to see why the engine builder is willing to install an unusually large engine, provided the customer can be persuaded to pay for apparatus of such abnormal capacity. By the use of such a method for determining the size of engine, it would be only natural to simply guess at the size of flywheel. Supposing the flywheel should be too small, the engine must take more than its share of the peaks. With this condition the engine builder may be misled into believing that his engine is none too large. Very comprehensive data are necessary to determine definitely the size of motor and flywheel required, considering the two as a unit, their relation to each other depending to a large extent upon the type of control used. Almost any engineer can specify the drive of a mill if he is allowed a large factor of safety, but good engineering and commercialism demand accurate knowledge of the subject.

It is stated that a low rate of displacement probably requires less power than if the metal were rolled quickly. Could this be attributed to greater slippage between the metal and rolls at high speeds, which would introduce greater friction?

One of the advantages of automatic speed control is that the losses in the external resistance of a motor are reduced to a minimum. It is well known that very often rolling mills run idle a fairly large percentage of the time. During light load the secondary resistance is automatically short-circuited, which, with no losses occurring in external resistance, gives the best possible efficiency. With fixed resistance in secondary, energy is dissipated in this resistance which makes it impossible to obtain a high efficiency even at light load.

I note that in Table I of Mr. Sykes' paper the last four columns of passes one and two have been left blank. This has probably been done not to complicate the calculations too much. It is evident that the motor can return 2197 h.p-sec. during the five seconds interval, but during the intervals after the first and second passes, only 1092 and 2167 h.p-sec. are required, respectively, to bring the flywheel up to speed. This is true only of the first slab put through the mill after the motor has been running idle long enough to come up to light load speed, but if the schedule is followed as shown in Fig. 11 when the second slab enters, 1135 h.p-sec. are still required to bring the flywheel up to light load speed. This shortage is made up during the intervals after the first and second passes by the motor returning 2197 h.p-sec. to the flywheel in each case, instead of 1092 and 2167, respectively.

Wilfred Sykes: In Mr. Wilson's discussion of the first paper he refers to the use of flywheels being a necessary evil. That is quite true. But the flywheel makes it commercially feasible to drive rolling mills electrically, which, in the majority of cases, would otherwise not be possible. The diagram referred to in the discussion, that is, the one given in the paper, is actually made up from tests on a plate mill, in fact, it is the result of the test, modified somewhat to give it in round figures, but for all practical purposes they are the test figures obtained.

Mr. Wilson refers to the possibility of carrying the peak loads to the power station. The universal complaint that one hears from the operators in steel mills is that their power stations are all fully loaded, and they never have enough generator capacity to carry the load, and anything that produces a peak is about the most undesirable thing they can think of, next to something that will give them a bad power factor.

Mr. Haar in his discussion referred to the differences that exist in tests that have been published. I have studied some of these tests rather closely, and I believe a good deal of the difference is due to the method of testing. Some years ago, I had some work to do, involving such testing, and we did not know before starting what the difficulties were, and we got all sorts of results, and exactly the same thing occurred in tests referred to in this discussion. That is why it was necessary to make a preliminary test extending over about two months. It took that time to train the people so that they would operate the instruments properly and get the information accurately. One of the most difficult things was to get all the information, in the first place, and after we had the observers trained properly so that they would get all the information, the next difficulty was to get the information correctly. The preliminary results which were obtained varied several hundred per cent and were wholly unreliable. It was after the people had been trained for a couple of months to work together that they reached such a state of perfection in their operations that they could go into a mill and make tests which would be reliable from the beginning.

A great deal of this trouble was due to the fact that we did not appreciate the necessity of calibrating our apparatus often enough. We thought if we calibrated it once a day it was all right. Actually, we found we had to calibrate the apparatus after every test, and that is not an easy proposition, and involved the employment of a great deal of apparatus.

Mr. Cheney has brought out very well the subject of power factor. It is often asked, " Why don't you put in a motor that is big enough to carry the load, so that there will be no doubt about it?" In some cases they have such machines, and they do not know how to run the generating stations on account of the low power factor.

Mr. Westcott referred to the tests on steam-driven mills. In that connection I think it might be well to refer to a type of steam indicator that has been developed in Europe by Rosenkranz. This indicator has been used in Europe, and to some extent in this country. When you make a test with an ordinary closed diagram the lines get so mixed up that in many cases you cannot make out where one diagram begins and the other ends, and under such circumstances it is difficult to get accurate results. Instead of using a closed diagram Rosenkranz brought out an arrangement of diagrams which has the appearance of an ordinary graphic recording meter chart. This indicator makes it possible to make fairly reliable tests and secure reliable results from steam mills, where it was not possible to obtain very consistent results with the ordinary closed indicator diagram.

Regarding the method used for obtaining the section when rolling heavy materials, such as angles, channels, etc., we have managed to persuade the mill people in a great many cases to run out a piece after a pass so that we got a section of it. We did not always succeed in doing this. If they were not very busy we managed to get them to do it, but it was not always easy.

The paper was driven from a countershaft, all instruments being driven by the same countershaft, and the whole thing driven by a little motor, from a storage battery, or sometimes directly from the lighting circuit. The speed stated in the paper, of one inch (25.4 mm.) per second, was not always used. We arranged the speed according to the class of mills with which we were dealing. If we had a rapidly fluctuating load the high paper speed was employed. If the load did not fluctuate, then a lower speed was used. In all of these tests we never succeeded in getting the people to slow down their mills to accommodate us. All the tests were made while the mills were running at their normal rate of production, and that complicated the matter a good deal.

Mr. Petty asked if any information was available as to the effect of the rate of displacement. The effect of the rate of displacement is not very great, so far as I can determine, and the whole thing is so covered up with other factors, that I am doubtful, without making a series of investigations especially with that object in view, if it is possible to say definitely what effect it has upon the power requirements.

Referring to the second paper, the scheme of using a synchronous converter connected to the rotor circuit of the alternating-current motor, mentioned by Mr. Crosby, I believe is the scheme developed by one of the European manufacturers. This scheme has been used in the past to quite some extent, but it is not being used at the present time to any extent. In the past it has been used principally in connection with fans for mine work, and so long as you have a suitable frequency, like 50 cycles, as in Europe, this scheme works all right, because if you have 20 per cent variation, you have 10 cycles for the synchronous converter, and the conditions are not too bad, but when you deal with 25 cycles, the usual frequency in steel mills, and want such a range of speed, you have to design the synchronous converter accordingly for 5 cycles, and you necessarily have to use a large machine and the cost of this arrangement, not the efficiency, is, I think, its main drawback. It involves the use of a synchronous converter, driving a direct-current machine, which may be either connected to the shaft of the main motor or used for driving an induction generator. It involves two or three additional machines, and is somewhat complicated.

That brings up the point, in connection with mining work, especially in this country, that you must look out very carefully for anything that introduces complication. The more machinery or control apparatus you have, the more trouble you will have with the system.

The point brought out by Mr. Robinson covers one of the difficulties we ran into. It is quite true that the spark has a tendency to jump around, and we found it was necessary to make pretty careful arrangements to insure that the paper went evenly over the board in which the plate was recessed. Then, in addition to that, we had to use a special paper, to avoid spreading of the spark. We also found out that the material used for the spark point had a great deal to do with the matter. If we used platinum and shaped it properly we got good results. We used rather a light spark, which did not burn the paper, but the puncture could be distinctly seen by holding the paper to the light. After the test was made, the sheet of paper was placed on a plate of glass and the curve drawn in by hand. In that way it was possible to avoid the difficulty of the spreading of the spark, and I do not think in any case the mark of the spark was more than 0.01 in. (0.25 mm.) wide in the tests we made after the preliminary experiments were made.

DISCUSSION ON "PERMEABILITY MEASUREMENTS WITH ALTERNATING CURRENT" (ROBINSON AND BALL), AND "MEASUREMENTS OF MAXIMUM VALUES IN HIGH-VOLTAGE TESTING" (SHARP AND FARMER), BOSTON, MASS., JUNE 28, 1912. (SEE PROCEEDINGS FOR JULY AND JUNE, 1912.)

(Subject to final revision for the Transactions).

E. D. Doyle: As has been suggested in the paper by Messrs. Sharp and Farmer, the electrostatic voltmeter should have small leakage losses. If the voltmeter has low insulation resistance, it will not hold its charge but will discharge according to the exponential law

$$e = e_0 \epsilon^{-t/rc}$$

where e_0 is initial voltage,
e is the voltage at time t,
c the capacity of the voltmeter
and r the resistance of the leakage path.

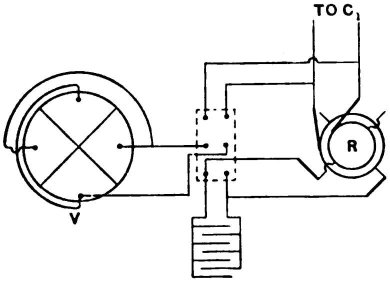


FIG. 1A

Hence the voltmeter will not indicate the maximum voltage, but one depending on the root-mean-square charge on the voltmeter between times of contact.

The effect of leakage can be largely eliminated by connecting a large condenser in shunt across the voltmeter terminals. The condenser acts as a storage reservoir and takes a large enough charge during the instant of contact to supply the leakage losses during the remainder of the cycle without an appreciable fall in potential.

A double-pole, double-throw switch connected as shown in Fig. 1A allows the condenser in shunt to be used for maximum indications and to be cut out for virtual indications. This arrangement has the further advantage of enabling all readings to be taken without stopping the synchronous motor.

In order to show the effect of the condenser in shunt, tests were made on a given voltage wave with various artificial leakage paths between the voltmeter terminals. The results were as follows:

Leakage path—megohms	Shunting condenser microfarads	Peak factor
16,000	none	0.87
1,000,000	"	1.35
50	0.1	1.35
1,000,000	0.1	1.35

From the above it can be seen that with a 0.1-microfarad condenser in shunt the resistance of the leakage path may be as low as 50 megohms without causing trouble, whereas operation is impossible without the shunting condenser if it is 16,000 megohms. The insulation resistance of the voltmeter was originally 8,000,000 megohms but has fallen to approximately 1,000,000 megohms. However, with the capacity in shunt, little trouble is anticipated from surface leakage.

The operation of the apparatus is now very satisfactory. The voltmeter is nearly dead beat and readings can be taken rapidly. Unless the voltage wave is very peaked, brushes do not need to be shifted until the voltage has passed through a wide range. The apparatus should be very useful in high-voltage tests.

M. G. Lloyd: A method for determining permeability by alternating current seems very important. I am glad to see a method proposed for doing that. Of course, methods have already been proposed along that line, but cannot be regarded as entirely satisfactory. In many cases, no doubt, the designer would prefer to have the value of the exciting current rather than the permeability curve, to use in designing; in other cases it is valuable to know the actual permeability at each value of flux density. This paper by Messrs. Robinson and Ball seems to indicate a way in which they may eventually be combined, at least in certain cases.

I think it is necessary, however, to bear the limitations very strongly in mind. It is shown, in the first place, that the maximum exciting current does not correspond to the magnetizing current which gives the maximum flux. This is brought out in the curves of the paper, and can be illustrated very well, if the hysteresis curve, or perhaps more properly, an energy-loss curve, is plotted in cases where there are eddy currents or energy supplied to secondary circuits. In some curves that I determined some time ago under such conditions* the difference from the static hysteresis curve was brought out in a very pronounced way. When the static curve is determined for hysteresis, it is found to go up to a sharp point at the corner of the loop. On the other hand, if the curve is determined with alternating current, and with the existence of eddy currents, that corner becomes rounded off, showing in a very marked way that the maximum exciting

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**Bulletin* of Bureau of Standards, V, page 402; 1908.

current does not correspond with the maximum flux-density. The oscillographic curves in this paper bring out the same thing. Some of the limitations have been expressed by the authors. One of them which is emphasized, is that the specimen must be thin enough to avoid magnetic screening. Another one, which is perhaps not emphasized enough, although it is definitely stated, is that the assumption is made that the eddy currents are in phase with the e.m.f. which produces them. Now, as a matter of fact, that is not generally true, and, of course, the more prominent the eddy currents become, the greater the effect which would be occasioned by the fact that the assumption is not entirely warranted. So that this method, while it may prove to be practicable in certain cases, is likely to be very limited in its application.

We have been in the habit of thinking of the oscillograph as an instrument for simply drawing curves of wave form. In one of the papers presented at the Boston convention, by Professor Harding, we saw how it could be used in making measurements of other quantities than wave form, and here we have an instance of its use in measuring the maximum value of a quantity, and in a case like this the maximum value can be determined without actually drawing the curve, merely observing the deflection on the oscillograph scale. It occurs to me that in the case of maximum voltage, as in the paper presented by Dr. Sharp and Mr. Farmer, it might prove a very convenient means of getting the maximum value. I do not think it would have the accuracy of the method presented by them, but in cases where the highest accuracy is not needed, and the oscillograph is sufficiently accurate, my experience with rotating commutators would indicate that it might be a much more satisfactory method for doing rapid work.

Clayton H. Sharp: I wish to point out the difference that the method I have referred to is one which requires no current. I do not know how you can use the oscillograph without consuming current. The electrostatic voltmeter, once charged, stays charged. There is the difference between it and the oscillograph, and it is a fundamental difference.

As to rotating commutator not being satisfactory, the same statement applies—the poorest kind of contact is sufficient, because it is only a question of charging the condenser. Not only that, but the use of an actual voltmeter rather than an oscillograph is obviously a desirable thing.

T. W. Varley: What percentage of your contact is the width of the contact relative to the width of the sign? How much of the contact do you lose?

Clayton Sharp: Probably not over one per cent. It is very narrow.

L. T. Robinson: I was much interested in the term used in Dr. Sharp's paper, " peak-factor." It seems to me to be a very good one, but I think it is new. We have used the term " amplitude-factor " that was coined some years ago by Dr. Fleming, which, if I understand correctly, is the reciprocal of this term, and previous to the use of the term "peak-factor," we have had employed in some English publications the term "crest-factor." I like "peak-factor" better because it is quite commonly stated when things happen to the wave that the wave becomes peaked, and the fact of its becoming peaked could be, I think, properly expressed as "peak-factor."

It was intended to point out in Mr. Ball's paper, with which I had some slight connection, that this method never can be exactly right, but we were dealing with practical matters entirely, that is, there was no intention to enter into it from the standpoint of exact theory.

With reference to the eddy currents being out of phase, the best we could figure out along that line was that if there were appreciable screening the eddy current would be out of phase. If there were not, it would be in phase. If there is appreciable screening the method gives incorrect values, because the magnetic density determined by the voltage on the secondary winding would indicate the average value over the sheet. The average value, so determined, would not be the uniformly distributed induction through the sheet, which must of necessity be known in order to plot correctly the *B* values against the maximum magnetizing current.

The intention of the paper was not to speak of the advantages and wide scope of the method, but to call attention to the fact that even in the cases shown, which seem to be the most favorable kind of samples, that is, samples of iron with low eddy loss, very low indeed, and thin sheets, etc., there is found a tendency of the maximum primary current to exceed the magnetizing current which should be plotted in connection with the *B-H* curve. At least, the total current had a definite tendency to be so large at maximum as to exceed the magnetizing current, but at the same time the difference was not so large but that it still looked a little hopeful to us.

Elihu Thomson: I would like to say a word about the term "peak-factor." I think it is a good suggestion, but I would like to see "wave-peak-factor" the term, which would define the peak-factor intended. We use the word "peak" in so many significations, peak of the load, etc., that I think the term should be qualified. Of course, if the context of the paper shows what it means it is all right, but as Dr. Sharp has coined the term, it seems to me as a measure of prevention of confusion it might be well to put the word "wave" before it.

Clayton H. Sharp: Regarding that term "peak factor," I did not mean to coin anything. It seemed to be a rather obvious term to use, and I simply used it, without considering whether it was new or old. I doubt if it is a new term, although it may be. I agree with Professor Thomson in his suggestion that the term might be more specific, and it might be made "wave peak-factor."

DISCUSSION ON " ELECTRICITY ON THE FARM " (BATES), BOSTON, MASS, JUNE 28, 1912. (SEE PROCEEDINGS FOR JULY, 1912.)

(Subject to final revision for the Transactions.)

J. D. Merrifield: Where I come from they sell electricity to the farmer at $50 a horse power, and he can use it for anything he pleases.

I want to speak of refrigeration. Mr. Bates states that every farmer can afford refrigeration. I will tell you of a refrigerating " plant " in use in my town. The humidity of the air there is very low. If you draw air through water and then pump air into the room by means of a fan, you will lower the temperature of the room six or eight or even ten degrees. Where I live the temperature goes up to 119 deg. fahr. in the shade, and I have known it higher. This may last a day or two. I know of a boy out there who rigged up a very successful device. It consisted of a rod from his wagon and the picket rope from the cow, and he made a little fan drive, put the fan on the kitchen window, hung wet cloths, and he cooled off both the kitchen and dining-room, and made it a very comfortable place to occupy. It is a very simple and yet a very effective method of accomplishing the result.

L. L. Elden: I hope before Mr. Bates leaves our country here in the East he won't fail to find out that at least one electric company is entering the field. The Edison Electric Illuminating Company of Boston has what is called an " Edison farm," about twenty miles from Boston, where all types of electrical machines and applications of electricity to these machines are on exhibition. The company is offering to extend its lines practically anywhere to get the business, and it is practically off-peak business. It is therefore very attractive to the company from both the capacity and income points of view. I do not know whether this exploitation has been attempted elsewhere, and we do not know exactly what the result of this effort is going to be, but so far there has been a marked interest displayed by the neighbors in the vicinity of the exhibit, and sales of several large motors have been made for farming purposes.

Putnam A. Bates: I have known something of the idea that this company was planning, and I am very glad to hear that the project has been put into actual operation this year. There is no question that it will take a little time before the additional expense of such an exhibit is brought back, but when it comes back it will come back strong and the companies that make their beginning now will be the ones that will profit the most. The sale of electric machinery among the farmers, as I have pointed out, is going to be tremendous. The sale of electrical energy is going to be even more tremendous, because in five or ten years at the outside, it will be a most unusual thing to see a farm without electric current in use for both lighting and power.

I can recollect when dentists used a hammer, to drive the filling into one's teeth, but they don't do that now. A little electric motor has been substituted for the hand method. I have worked my own garden with a hand wheel hoe, but why should I not attach an electric motor to this device and let the motor do the digging while I merely furnish the energy to move the tool along? That is what was done with the big grain harvesting machines. They require forty or fifty horses or mules to pull them, the greater part of this energy being necessary to do the cutting, threshing and binding. Some ingenious fellow said, " Why not leave a good many of those animals in the barn, or sell them to the neighbors? Put a little gasoline motor on the back of that threshing machine. It is heavy already. It won't add much to put on a few hundred pounds more. Let the gasoline motor do the threshing and binding, and let the animals pull the thing about." That was a great improvement in harvesting machinery.

J. A. Moyer: I would like to ask Mr. Bates one question, whether he has any figures regarding the proportion of the individual or isolated plants used in comparison to central station power, where the latter is available.

Putnam A. Bates: If I understand the question correctly my answer must be that the isolated plant and the central station service for the farmer very seldom conflict. We might think they would, because in the city we find such competition always. But out in the rural sections the conditions are different. The central stations seem to be either progressive or hopeless. The former follow a liberal policy and cultivate the farmers' business. They are solving the problem from his point of view. With the latter class, we find the plants generally are carrying tremendous overhead burdens and have to charge from ten to fifteen or more cents per kilowatt-hour, and they insist on the farmer paying for the pole line if he wants the current. It is a ridiculous proposition. The farmer simply buys an isolated plant instead. You can compete with a ten cent service rate by having an independent plant.

You find that on the farm labor conditions work out differently from in the factory. In the factory you can differentiate between your candidates for employment. You can pick out the skilled man. You can let the others who apply go. But on the farm it is the other way around. You are mighty lucky if you get an unskilled man, to say nothing of the skilled man. These farm hands are pretty good as farmers. They usually mean well, but they will go along with the load of corn stalks to put into the silo and if you have a gasoline motor of 12 h.p. that is supposed to be ample to drive an ensilage cutter and silo filler they will put two bundles of wet cornstalks on the platform, and they will jam them in so as to stall a 12- or 15-h.p. gasoline motor every time. So really you ought to have 20 h.p. in a gasoline engine if you want to do silage work and do it right. Now with electricity you can use a 10-h.p. motor. It will cost less than a 10- or 12-h.p. gasoline motor, and rough treatment such as I have described makes no difference to the motor. It has 100 per cent overload capacity for a short time, and it will go through the heavy momentary overload with no delay or injury. That is one of the great advantages of electricity on the farm, it is so easily and well adapted to the needs of the situation.

Mr. Sanford: I would like to ask whether in the course of the daily work there is what you ordinarily call a peak load on the generator, that is, on a farm running with a small isolated plant, and, supposing there is any peak load which would tend to bother the generator, would it not be economical to carry a storage battery which will be charging during the light load and when the peak load comes on will be running parallel with the generator?

Putnam A. Bates: That is a good point: The storage battery is of no little significance in connection with the equipment of the isolated plant on the farm. I never design an isolated plant for farm use without putting in a storage battery and a good big one because that is just the factor that you need in a small rural isolated plant—a good big balance wheel to carry you over the times when you don't want to run your engine.

Adolph Shane (by letter): This paper has proved of considerable interest to me for several reasons. In the first place I have had occasion to look into this subject under the conditions surrounding my section of the country (Iowa)* and I desired to ascertain the view-point of another who had also made a study of this important development. In the next place, Mr. Bates has given me a clearer idea of the extent to which electrical apparatus for farm purposes has been developed. Again, he has shown the possibilities inherent in farm electrification.

Under certain conditions these possibilities may prove to be desirabilities. And this is the phase of the subject I wish to consider. To what extent is it desirable to electrify a farm? Mr. Bates shows us how extensive irrigation schemes are successfully carried out in the semi-arid West by means of electricity. He has shown us the application of electric power in the dairy and in the harvesting of ice. But does a comprehensive scheme of electrification under our present conditions represent advantages to the majority of farmers over this broad land? I think not. Until central station men see that it will pay them to sell cheap power to the farmer and until the farmer sees that his returns in dollars and cents are greater by the use of electricity than without, electrically operated farms will not become general.

The greatest farming sections of the United States are in the middle West. Because of the preponderance of farm production and wealth in this part of the country, the conditions as they obtain here should also fairly well represent the conditions over the country as a whole; and where other conditions exist elsewhere they might perhaps be taken as special and not typical.

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*See Bulletin No. 25, Engineering Experiment Station, Iowa State College, Ames, Iowa.

Let us then consider the farms of the middle West and study the problem of electrification.

In looking over the field we find that the farms, generally speaking, are many and moderate in size rather than relatively few and great in extent. On the large farm the problem of electrification may be taken seriously, but on the small farm the owner will have to be convinced of definite profits before he commits himself to the expense, especially since the middle western farmer does not depend on irrigation for his crops. But suppose he is considering electrification, what is to be his source of power? It must either be a central station or he must manufacture the power himself. As a rule the central station does not find it profitable to supply farmers with power in this region. The uses to which the farmer may desire to apply electric power are light, a number of domestic utensils, several motors of small power, and a large motor of perhaps 25 h.p. with which to thresh and cut ensilage. This latter motor is used but a few days in each year, yet it is necessary to supply transformers to take this maximum load. The result is that the load factor for the year is so poor that the all-day efficiency on the average is low. The result is that there is a considerable waste of power and the central station must charge more per kilowatt-hour for this reason and because of the relatively heavy overhead charges in proportion to the amount of power used. The latter reason may not exist if the transmission line is primarily built to serve a neighboring town and the farmer is taken on incidentally.

If the farmer is to manufacture the power himself he must, under similar conditions again, install a plant capable of supplying the largest motor with power, namely the 25-h.p. motor. Thus he would again, excepting for a few days in the year, operate his plant at a ridiculously small load factor. This would be aggravated by the fact that there would be little excuse to drive the churn and cream separator by an electric motor, since the gasoline or oil engine could drive a line shaft, which connects the power room with the repair shop and dairy room, at the same time that it operates the generator. This would be no less convenient and cleanly than the motor drive, for under any circumstances all apparatus should be operated at as nearly the same time as possible for the sake of economy in power generation; and the line shaft and belting is not more prominent in one case than in the other. I refer now to the dairy room of the average farm. Accordingly the cost of plant is excessive for the amount of power produced and the cost of power is excessive because of the very small load factor.

We thus see that the average farmer is at present enabled to use electric power only in a limited fashion; but if he is properly advised he may reap considerable benefit from the use of such power in a conservative way. The farmer realizes the convenience and safety of the electric light, particularly in the barn. Hence, aside from its cost, he may desire electric light. So I believe the use of electric power on the farm centers at present in the farmer's desire for electric light. In most cases he will produce the power himself, using a small gasoline or oil engine, generator, and storage battery for lighting. This is the entering wedge. If planned beforehand, the generator may have sufficient capacity to supply power for the flat-iron, washing machine, fan, sewing machine, etc., as well as to charge the battery, without causing the plant to cost materially more. The farmer may be ambitious and desirous of doing his grinding and pumping by means of electric power. He may still do this with a small capacity plant. But this is perhaps the extent to which, it appears to me, electrification should be carried by the average farmer at present.

If a number of farms operated a plant in cooperation the above discussion would be subject to considerable revision. But because of the human equation entering, general cooperation has hardly proved a success among farmers.

In the future the following causes may extend the degree of profitable electrification:

a. The increase in value of farm products to such a point that it may pay to multiply machinery for the more efficient and rapid handling of them.

b. The general development of large central station systems for the economic production and distribution of power.

c. The increase in size of farms under single or corporate ownership.

Any of these causes or combination of causes may produce the desired end. The point I desire to make in this discussion is that the members of the electrical profession interested in exploiting electricity for the farm will gain greater and farther reaching results in the end if such exploitation is followed along careful and conservative lines. The confidence of the farmer will then be secured.

Putnam A. Bates (by letter): Mr. Adolph Shane in his discussion of my paper " Electricity on the Farm " states: " under certain conditions these possibilities may prove to be desirabilities." And he adds the question: " To what extent is it desirable to electrify a farm?"

In answering this question, I must first emphasize the fact that in my paper I have not described possibilities, but have recited actual conditions of electrification on farms, many of which have been thus successfully operating for several years, a sufficient length of time to demonstrate fully their desirability.

The purpose of Mr. Shane's argument, I take it, is to awaken the central station man to the importance of aggressive co-operation in this application of electricity landward, and while in a measure I can sympathize with Mr. Shane, as my own farm in New Jersey lies in a section of electrical supply where the operators of the local plants are many years behind the times, generally speaking, the central station men are now quite alive to this problem, and it is a notable fact that during the past two years the progressive central stations in the United States and Canada have been making rapid strides in extending service to the farm. In fact, almost coincidently with the presentation of my paper at the Boston convention of this Institute in June last, the National Electric Light Association during its convention in Seattle discussed this subject and many important data were presented.

A few years ago, Mr. Shane's statement that the greatest farming sections of the United States are in the Middle West would have gone unchallenged, but today reliable reports do not show this to be so.

Unquestionably, the Middle West is deserving of great credit as a section of immense agricultural wealth, but in basing an argument as to the best equipments to recommend for the proper development of our farms in all sections of this vast country on the practises that now obtain there, more credit is being given than is due the Middle West, or any other one locality, for that matter.

The very fact that the Middle West has for so many years been regarded as a leader, agriculturally, is, I think, a sufficient reason for us to regard with suspicion any suggestion of impracticability regarding the recommendations of those who wish to see the advancement of new ideas in this field. It is in the new sections that we are most apt to find the early adoption of improved methods and not, necessarily, in those districts where an industry has long been successfully established.

The older agricultural sections must not remain too wedded to the methods of the days during which their reputations were making, for it is only through a continual application of new ideas, improving upon the old methods, that surpremacy can be maintained.

The increase in rural population during the past ten years has been decidedly in favor of sections other than our Middle West, and this is a straw that shows the way the wind is blowing. In Iowa, for example, the rural population has actually decreased and the same is true of Missouri, Indiana and Ohio, whereas in the other States of the middle western group the increase has been less than ten per cent. Against this, we find the increase in Washington, Oregon, Idaho, California, Nevada, Arizona, Colorado and other States to be 30 to 50 per cent, and in some cases even more than this. These figures are from the U. S. Government Census reports, 1900 to 1910.

A similar condition is indicated to us by a study of the acre crop yields of the middle western States compared with the old eastern States that are coming back into their own through the scientific treatment which these " wornout " soils are now receiving and the passing of the farms from weaker to stronger. hands. This fact is shown by the following figures taken from the reports of the Department of Agriculture of the United States for the year 1910 regarding the production of wheat, corn and oats since 1866. Reliable reports prior to 1866 are not available.

The production of wheat in the following States was:

	1866 to 1875	1876 to 1885	1910
Maine	13.2 bushels	13.7 bushels	29.7 bushels
New York	14.1 "	15.5 "	23.7 "
Pennsylvania	13.3 "	13.4 "	17.8 "
Ohio	12. "	14.6 "	16.2 "
Illinois	11.9 "	13.1 "	15. "
Iowa	12.6 "	10.2 "	21. "
Kansas	15.7 "	13.9 "	14.0 "

The production of oats in the following States was:

	1866 to 1875	1876 to 1885	1910
Maine	21.6 bushels	26.8 bushels	42.4 bushels
New York	21.2 "	30.5 "	34.5 "
Pennsylvania	30.6 "	30.2 "	35.2 "
Ohio	29.6 "	30.6 "	37.2 "
Illinois	30.5 "	33.2 "	38. "
Iowa	35.8 "	33. "	37.8 "
Kansas	32.8 "	30.6 "	33.3 "

The production of corn in the following States was:

	1866 to 1875	1876 to 1885	1910
Maine	29.3 bushels	33.8 bushels	46.0 bushels
New York	31.6 "	30.4 "	38.3 "
Pennsylvania	35.1 "	32.6 "	41.0 "
Ohio	35.2 "	32.6 "	36.5 "
Illinois	29.9 "	27.2 "	39.1 "
Iowa	34.3 "	31.8 "	36.3 "

One very important feature of the now much discussed subject of "electricity on the farm" is that where this improvement is found, it is universally accompanied with better conditions generally. The farmers are of a different frame of mind from those where the less efficient forms of energy are used for power and lighting. This condition I have noticed many times in different localities, and it is my opinion the most important condition of all, because this interest means better farming in all branches, and even if the electrical method were the most expensive, which it is not under a proper order of things, a comprehensive scheme of electrification would be justified on all farms worthy of the name and farmers will do well to adjust their present conditions so as to be not long delayed in the enjoyment of the advantages of electricity, no matter what agricultural section the farm is located in.

We would not think of recommending electric power for the textile mills of New Jersey and then advising against its use in the mills of Illinois. We would not say that the machine shop in New York State, where we will assume the power rate for electrical energy is from 5 to 10 cents per kw-hr., should be operated by hand-power whereas the shop in Colorado, where perhaps a 2-or-3 cent rate prevails, might indulge in electrification and the many resulting advantages therefrom.

Electric drive and electric lighting are too well understood for us to confuse in any way the importance of their advantages with the obstacles that are naturally encountered in the introduction of a new method into a new field.

Today, however, the farmer is independent of the central station, and yet where service is supplied at a fair rate with reasonable reliability, there may be advantages in some cases in not installing a private plant. In any event, the problem can be solved and the improvement well justifies the expense. This has been demonstrated in many places, under many conditions.

On all farms the problem of electrification should be taken seriously. On the small farm it may not pay to carry the idea as far as on the large farm, but again the reverse is sometimes true. In the small farm home, often times it is nearly impossible to secure satisfactory labor, and it is under such conditions that electrical energy is most useful. On small farms a large amount of power is seldom, if ever, required. The feed is ground when bought and threshing and other heavy work can be contracted for.

On the larger farms a greater precentage of the operations involved in converting raw material into finished products is undertaken, the average daily power requirement is greater, and the business enterprise is of sufficient magnitude to justify a gradual improvement in equipment and an ultimate adoption of the most efficient methods. This is an economic problem and one which is more important to consider on our farms than in our factories or mills. And from the facts already presented we know that the increased rate of handling work, the decrease in labor required and the actual economy of electrical power commend this form of energy for favorable consideration on the farm as elsewhere.

I must also differ with Mr. Shane in what he says in reference to the character of plant that would be necessitated under certain conditions which he has named.

While a 25-h.p. motor would be running less than half loaded when operating an ensilage machine in reasonably good repair, and slightly more than this when driving a threshing unit of average size let us take Mr. Shane's figure for the sake of argument. Manifestly it would not be good planning to load the entire year's service bills, where the ordinary day's electrical requirements are small, with the inefficiencies and overhead charges incidental to a service equipment that is out of all proportion to the average current demand. The idea of electrification of the farm should not be carried to this point.

The same principle is true in the designing of a private plant, but there the difficulty cited is more easily overcome through the introduction of a storage battery of sufficient capacity to carry large peak loads. In fact it is advantageous to have the battery of such size that it does not have to be charged every twenty-four hours, as here again we encounter the labor problem which is so difficult to arrange satisfactorily on the farm.

If the plant be so designed that the generating set is of sufficient size to carry the evening lighting load direct and to charge the storage battery during the daytime, and the battery is large enough for the heavy peak loads when unusual work is being undertaken, it is better, even if it takes several days to charge the battery fully, than it would be to have a generating set of sufficient capacity for the maximum demand and only a small battery or none at all.

Now one word about electricity in the dairy. Mr. Shane speaks of possibilities and desirabilities of electricity on the farm. Let me say that when clean milk is selling wholesale at from 7½ to 15 cents per quart net to the farmer, as it is today in New York State and New Jersey, Massachusetts, Connecticut, Pennsylvania, Maryland and doubtless elsewhere, there is little question of the desirability of using electricity for both lighting and power, no matter what may be the source of electrical supply. For the introduction of electric light and power devices in our high-class dairies has done more toward bringing down the bacterial count in milk than any one other feature of equipment, except sterilization facilities and proper means of cooling.

In the creamery, it is not a question of economic use of power that prompts the use of the direct-connected or closely belted motor-driven separator and similar sanitary devices, but the elimination of dust-stirring parts and vibrations and uneven speeds which reduce both the quantity and quality of creamery products.

To define the possibilities of electricity on the farm would be to design an ideal installation with an infinite number of uses for this form of energy. This I have not attempted to do in my paper, but instead have confined myself wholly to descriptions of actual installations and the submission of data from which all may benefit in dealing with this problem in individual cases.

In closing, I would, therefore, point out that the electrician must get his point of view in this matter from the needs of the farm in question and select his equipment on the basis of a proper economic treatment of the problem of the management of the farm as a whole. He must not reason from the standpoint of the farmer who is today poorly equipped with apparatus or knowledge as to scientific agriculture. The farm is a factory and in the profits of its output will be reflected the skill with which its operations are managed.

Electric light and power are used everywhere else in our industries of the day and it is only through lack of confidence in the possibilities of success in farming as a business that anyone would be justified in denying this great improvement to the farmer.

The points which Mr. Shane raises come really under the heads of " farm management " and " plant design." And the answer as to whether any particular farm should be electrified or not must rest with the farmer himself. I need only add, as a guide to anyone in such a position, that the value of the farm as a producing proposition should be determined and its operating conditions noted. If then the business enterprise is of sufficient magnitude or of such character as to justify an important improvement for safety against fire risk, or for improved and increased production with greater economy of operation, then find a way to electrify and carry this as far as the state of the art may permit, or as far as one experienced in these matters would advise.

DISCUSSION ON "OPERATING CHARACTERISTICS OF LARGE TURBO-GENERATORS" (FIELD), AND "THE TRANSIENT REACTIONS OF ALTERNATORS" (DURGIN AND WHITEHEAD), BOSTON, MASS., JUNE 28, 1912. (SEE PROCEEDINGS FOR JUNE, 1912.)

(Subject to final revision for the Transactions.)

H. M. Hobart: I consider Mr. Field's paper to be an excellent statement of the situation in regard to turbo-generators. Developments of the last few years have made it quite necessary to introduce considerable deviation from what was formerly considered the best design. This has come about largely from the necessity for better construction because of the stresses due to the large short-circuit currents, and for other reasons.

My attention was attracted by the last paragraph of the paper, in which Mr. Field recommends the avoidance of handicapping the design of the alternator to any extent as the result of incorporating the ventilating fans in the design. I am strongly inclined to believe that he is quite right. It always seems to me that a characteristic feature of almost all engineering methods is that the engineer's work will be more in accord with the strict commercial line of progress when he is free to let each element in the engineering work be adapted to its own particular purpose. In large work at any rate, this policy is generally in the interest of true commercial economy, and I believe with Mr. Field that it will often be preferable, where the generators are of very large capacity, to provide completely independent ventilating apparatus. This plan has various advantages. If we try to incorporate the fans we handicap the design of the alternator. The design of the alternator cannot be quite as good as if that requirement was not in the designer's mind. Moreover, if the ventilating apparatus is distinct from the generator, that apparatus also can be made more efficient and appropriate.

Occasions will often arise where a centralized ventilating plant can be successfully employed. One reason for that, as Mr. Field suggests, is that the air can be treated before it is sent on its way to the machine. Great developments are in store in this direction. It is a very important matter indeed that the air should be thoroughly cleaned. That can be best done as a separate department of the business. The humidity of the air may also with advantage be controlled prior to sending it on to the machinery through which it is to be circulated. Moreover, there are many otherwise fine stations which could be distinctly improved were the air taken from outside, as of course is done in many other stations, circulated through the machine, and sent—not into the engine room—but again outside, at any rate in many seasons of the year. In those seasons of the year where it would be useful to have it sent inside, it could be readily arranged. So that from every standpoint—from the standpoint of getting the very best generator for the money spent on it, the very best fans for the money spent on them, from the standpoint of having the air clean and in the most appropriate condition before entering the machine, and from the standpoint of having the most appropriate condition in the engine room, Mr. Field's suggestions are excellent.

B. G. Lamme: I wish to make a few general remarks on the paper of Messrs. Durgin and Whitehead. It is now, I believe, pretty generally accepted that all large alternators should have considerable reactance. You should put all you can inside, and if that is not enough, then put some outside. In some types of machines it is difficult to get enough internal reactance. There are some advantages in both arrangements. For instance, if a short circuit occurs in one machine, an outside reactance between the machine and other machines will protect the other machines. On the other hand, if a short circuit occurs at the winding of one machine, you may save that machine by having a high internal reactance, regardless of the other machines. A good proportion of the short circuits that occur in turbo-alternators are in the end windings and, in many cases, in the terminals. In those cases, if a ground occurs on the machine, the internal reactance may still save the winding and it may damage the machine only slightly. If a machine has very little internal reactance, then in the case of an internal short circuit or ground, the whole machine may be ruined; so there are some advantages in having considerable internal reactance, and also some in having additional reactance for protection against other machines. I am a great believer in having high reactance in the machine, and also, wherever necessary, in putting some outside.

In connection with the effect of armature short circuits on the field winding, in the New Haven Railway power house, when we first installed the generators, we had many short circuits on the trolley system, and we had more trouble at first in the generator field windings than in the armatures. Some of these troubles consisted of short circuits or grounds which we could not explain for awhile, but later we discovered that they were due to the high voltage generated in the field windings at the time of the short circuits on the line. We then put a low resistance shunt across the exciter circuit. That helped matters. Somewhat later we equipped the rotors of these machines with very heavy copper dampers, of the cage type; after that all trouble with field windings disappeared. That was four years ago. The dampers on the machines have suppressed the voltage rises, as was expected, and the field trouble has entirely disappeared, thus showing the effect of the cage damper in protecting the field winding.

P. M. Lincoln: I note that Messrs. Durgin and Whitehead in their paper have developed a formula by which they may obtain the maximum current in a short circuit and also the torque that is developed by the short circuit. I am not prepared to discuss the accuracy of this formula because I have not had a chance to study it sufficiently, but I would like to ask whether or not any of the members have really come across any difficulties due to the torque which has been developed on any generators due to short circuits. Generator shafts are usually so constructed that the amount of torque which can be transmitted is very much in excess of normal full load torque, and there is so much excess that, so far as my experience goes, there is sufficient so that, whatever abnormal torque is developed by short circuit or any other condition, there is no difficulty. This formula, I believe, gives a comparatively small excess above full load torque as the maximum that can be obtained, amounting to perhaps two or three times the normal full load torque. This seems to bear out the experience stated above, viz.: that no difficulty may be expected from the torques due to short circuits.

Henry G. Reist: Some years ago, when we did not fully appreciate the stress of the high current that we get in generators, we had an experience with a generator which did shear coupling bolts, and I think there must have been nine or ten times the normal torque in the machine in order to have done this. Of course later machines are designed very much more cautiously and do not cause any harm. But there is no doubt in my mind that the torque in the older machines in the case of short circuits went up as high as ten or twelve or perhaps fourteen times the normal torque.

B. G. Lamme: In regard to the point Mr. Lincoln has raised regarding the torque, it may be said that the torque is developed in the alternator itself, but the transmission of this torque to other parts is a question of how much of it will be absorbed in the alternator rotor itself and how much in the other parts. In large high-speed turbo-alternators the rotor will absorb considerable of it. I know of one case of a turbo-alternator that had a special coupling on it, that was figured out to stand a maximum of three times the rated load. That machine was subjected to severe short circuits frequently, which in several cases affected the armature winding, yet the coupling was never injured.

Henry G. Reist: I think that might be true on some machines, but on a steam turbine generator the effect is large in comparison with the revolving part of the generator, so that a short circuit on the generator would transmit a great deal of stress to the coupling.

B. G. Lamme: The case I refer to was an engine-driven generator.

Henry G. Reist: On engine-driven generators I might state that I have not found much sign of excess.

In regard to Mr. Field's paper, I heartily agree with the author and I would like to add that the engineers of this country should, I think, as rapidly as possible, filter the air for turbine alternators. It is done, if at all in this country, practically on a very small scale, but it is a matter of very great importance, a method of great merit, and this country is far behind what is being done in Europe. It is the almost universal practise, abroad, to have the air for cooling turbine alternators filtered through cotton cloth filters. I think it is open to question whether the form of filters that they use in Europe is the best or whether some other form may not be better, but it seems to me it is a problem that American engineers should work out and then adopt the method which seems to be best adapted for the purpose.

Comfort A. Adams: There is one point that I wish to consider briefly; it relates to the internal and transient reactances. The difficulty in dealing with the internal or leakage reactance of an alternator armature is twofold. Not only is this term very loosely defined and loosely used, but the quantity, when once defined as accurately as possible, is still practically impossible of even reasonably accurate measurement, unless defined in terms of the results of some specific tests, in which case the result is pretty sure to involve different phenomena in different types of alternators. It is even more difficult to compute than to measure, and there is no accurate method of checking the computations. For example, I seriously question the estimate of two per cent as the reactance of the machine in question. Ordinary short-cut methods of computing the leakage reactance are likely to give very erroneous results when applied to an extreme type of alternator such as that referred to in the paper. A method which serves very well for one type of machine may be useless for another, unless it is completely rational. For example, any method which groups the coil-end reactance with the slot reactance on the assumption that the former is relatively small or that it bears a fixed relation to the latter, will yield much too small results for this type of machine, since the slot reactance is inversely proportional to the peripheral velocity and the coil-end reactance is directly proportional to the cube of the peripheral velocity, other things being equal. Thus if we step from an engine-driven alternator with a peripheral velocity of 100 ft. (30.5 m.) per second to a turbo-alternator with a peripheral velocity of 300 ft. (91.4 m.) per second, the ratio of coil-end to slot reactance will increase to 81 times its first value, other things being equal. This enormous jump is of course partly neutralized by the lower coil pitch commonly used in the high-speed machines, but remains inevitably large and in great measure dependent upon the coil pitch. The belt leakage also becomes quite appreciable at high peripheral velocities, although it varies tremendously with the coil pitch, being a maximum at full and two-thirds pitch, and a minimum (practically negligible), at $\frac{5}{6}$ and $\frac{1}{2}$ pitch, for a three-phase machine.

It should also be observed that the definition for x_F given in the middle of page 903 is merely descriptive or qualitative rather than workably quantitative, owing to the serious difficulty in defining and computing the field reactance, or what might for the present purpose be more appropriately designated the *equivalent* field reactance.

A question has been asked in this discussion as to the cooling effect of moisture in the air supplied to a piece of working apparatus. I have had recent opportunity to observe a case where the temperature rise of a machine under test was reduced eight deg. cent. or 25 per cent by the presence of considerable quantities of condensed steam in the air supply. After the air had passed through the machine there were no visible signs of the moisture, which had obviously evaporated.

A. B. Field: It is very satisfactory to find engineers of the experience of Messrs. Hobart and Reist standing out for air filtration in turbo installations. There seems little doubt that, if our manufacturing companies will strongly advocate the adoption of such processes, the operating engineers will be only too ready to see the advantages and install suitable apparatus.

Professor Adams has referred to the reactance introduced by the end connections of the stator winding. A considerable proportion of the reactance which is effective on a sudden short circuit is due to the part of the winding external to the core. However, in large two-pole machines, it is generally not feasible to adopt a coil pitch which is equal to the pole pitch, or even nearly so. The length of coil external to the core is already much greater than that of the buried portion, even when the coil is chorded considerably; the difficulties of satisfactorily clamping the ends increase with too great a coil throw; the rotor span, between journal centers, becomes lengthened, and further, in those cases in which complete coils are used instead of half coils, it is necessary to proportion the coil so that it can be passed through the bore of the stator for assembly purposes.

Sanford A. Moss (communicated after adjournment): Exception must be taken to Mr. Field's statement that it is difficult to provide for efficient and satisfactory blowers mounted directly on the rotor. Considerable experience with direct-mounted blowers of the type shown in Fig. 20 of the paper by Messrs. Hobart and Knowlton, *The Squirrel-Cage Induction Generator*,* shows that they can be made very satisfactory.

Blowers of this type, if properly designed, and if made with proper diameters, blade angles, etc., can be made fully as efficient as any separately connected blower, and often more efficient. The peripheral speeds are, of course, very high, but with proper design of blades this does not serve in any way to decrease the efficiency. One fact which makes a properly designed direct-mounted blower more efficient than a separate blower is that there are no separate rotation losses. The blower, being mounted directly on the rotor, has no disk losses of its own. Actual tests of machines with carefully designed blowers of the type above referred to, first with blower vanes removed and then with vanes in place, show that the increased power required for driving bears a very favorable relation to the theoretical power required for compression of the actually measured volume of air to the actually measured pressure.

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*PROCEEDINGS A. I. E. E., June 1912, page 1067.

The room taken by the blower itself is negligible and does not increase the length of shaft in the designs referred to. There must always be a certain space left for proper passages for carrying the air to the various parts to be cooled. These air passages must exist whether the blower is directly mounted or separately mounted. They, of course, take up some room, which is inevitable and due to the necessity of ventilation; not to the direct mounting of the blower on the rotor. The use of air filters with the direct-mounted blower is as convenient as, if not more convenient than with separate blowers. In all cases air should be taken from some outside source by a conduit leading to the blower inlet. It is very bad practise to take air directly from the engine-room even with a direct-mounted blower. The air filter can, therefore, be placed at the beginning of the conduit leading the air to the blower.

The method of ventilation by use of a high-pressure jet which Mr. Field mentions would be very inefficient. Most schemes of moving air by injector action entail large losses.

H. R. Woodrow (communicated after adjournment): I would like to ask the question why the reactance of the field circuit and the reactance of eddy current paths on contiguous metal masses reduced to armature are to be added, since they are in parallel? And also, is the reactance in the exponential function the value called " transient impedance?"

The maximum instantaneous torque is not the sum of the I^2R losses of the armature, but many times that value, since there is considerable energy required to build up the field of the armature reactance. Also the field current rises to enormous values, requiring energy from the generator.

Assuming the equation (**6**), in the paper by Messrs. Durgin and Whitehead, is correct for the armature current, although it cannot hold true for any appreciable length of time (1 to 2 cycles), that is,

$$i_1 = \frac{E}{z} \left[\cos (\theta - \theta_0 - \theta_1) - \epsilon^{-r/x\,\theta} \cos (\theta_0 + \theta_1) \right]$$

where the voltage is

$$e_1 = E \cos (\theta - \theta_0)$$

the instantaneous power is equal to

$$p_1 = e_1 i_1 = \frac{E^2}{z} \cos (\theta - \theta_0) \left[\cos (\theta - \theta_0 - \theta_1) - \epsilon^{-r/x\,\theta} \cos (\theta_0 + \theta_1) \right]$$

or, for any phase a in an n phase machine,

$$p_a = e_a i_a = \frac{E^2}{z} \cos \left(\theta - \theta_0 + \frac{2\pi a}{n} \right)$$

$$\left[\cos \left(\theta - \theta_0 - \theta_1 + \frac{2\pi a}{n} \right) - \epsilon^{-r/x\,\theta} \cos \left(\theta_0 + \theta_1 + \frac{2\pi a}{n} \right) \right]$$

The total instantaneous power on the shaft is the sum of that on the individual phases

$$p = \sum_{a=0}^{a=(n-1)} e_a\, i_a$$

which reduces to

$$p = \frac{3}{2}\,\frac{E^2}{z}\,[\cos(\theta_1) - \theta^{-r/x\,\theta}\cos(\theta + \theta_1)]$$

If z is represented in per cent, and on non-inductive full load $z = 1$, $\cos\theta_1 = 1$ and $\epsilon^{-r/x\,\theta} = 0$ and the full load power P is

$$P = \frac{3}{2}\,K\,E^2 \text{ or } K = \frac{2}{3}\,\frac{P}{E^2}$$

Hence the instantaneous value of power in terms of full load power is

$$p = \frac{P}{z}\,[\cos\theta_1 - \epsilon^{-r/x\,\theta}\cos(\theta + \theta_1)]$$

and

$$\cos\theta_1 = \frac{r}{z}$$

Then

$$p = \frac{P}{z}\left[\frac{r}{z} - \epsilon^{-r/x\,\theta}\cos(\theta + \theta_1)\right]$$

and the instantaneous power is independent of the point of the voltage wave at which the circuit is closed, but is pulsating in magnitude so long as the transient expression of current exists.

Assuming the expression for current to hold true for the first cycle, and a condition where

$$x = 10\,r,\quad z = 7 \text{ per cent},\quad \theta_1 = \tan^{-1}\frac{X}{r} = 84 \text{ deg. } 18 \text{ min.}$$

and

$$p = \frac{P}{0.07}\,[0.1 - \epsilon^{-0.1\prime}\cos(\theta + 84 \text{ deg. } 18 \text{ min.})]$$

the instantaneous values of power or torque will be as shown in Curve 2.

To determine the maximum point of the torque, differentiate the above expression with respect to time θ and equate to zero.

$$\frac{\delta p}{\delta \theta} = -\frac{P}{z}\left\{\frac{r}{x}\epsilon^{-r/x\,\theta}\cos(\theta+\theta_1) + \epsilon^{-r/x\,\theta}\sin(\theta+\theta_1)\right\} = 0$$

and

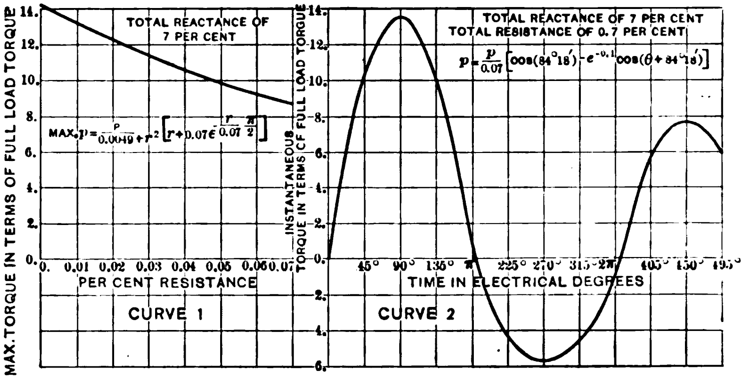
$$\frac{\cos(\theta+\theta_1)}{\sin(\theta+\theta_1)} = -\frac{r}{x}$$

hence

$$\theta = \frac{\pi}{2}$$

Therefore

$$\max p = \frac{P}{z^2}\left\{r + x\,\epsilon^{r/x\ \pi/2}\right\}$$



Max. p with respect to the armature resistance is plotted in Curve 1, which shows that the maximum instantaneous power occurs with zero armature resistance in a circuit of constant reactance.

With n generators operating on a bus when a short circuit of resistance r is made on the bus, the effect on the individual generator is the same as if $n \times r$ resistance were in each individual generator, hence the maximum instantaneous torque on the individual generators occurs with but one machine operating on the bus.

W. L. Waters (communicated after adjournment): The history of the turbo-generator has been one of continually increasing speed to meet the requirement of efficiency in the steam turbine, and it is only during the past few years that it has become possible to operate the generator at any speed found advisable for the turbine.

An idea of the progress made can be obtained from the fact that 5000-kv-a., 3600-rev. per min. maximum rated units have been built in the United States, and 6000 kv-a., 3000-rev. per min. units with 25 per cent overload capacity have been built in Europe; while I understand that Mr. Field has designed and is prepared to build 30,000-kv-a., maximum rated, 25-cycle generators to operate at 1500 rev. per min. The question of high speed vs. low speed for turbine sets is similar to the question of high-speed vs. low-speed steam engines. It is to be decided by the relative cost, floor space, maintenance, and efficiency of the sets. One handicap of the high-speed steam engine is that when it gets out of adjustment, trouble develops very much more rapidly than with the corresponding low speed; but the same criticism hardly applies to steam turbine sets, as there is practically no difference in this respect between an 1800-rev. per min. and a 3600-rev. per min. unit.

The phenomenon which takes place at the instant of short-circuiting an alternator was investigated by the writer a number of years ago, when it was found that on account of the eddy currents there was a time lag in the effect of the armature reaction in reducing the flux. So that—as I think was first stated in the paper on *Non-Synchronous Generators*, which I presented before the Institute in February, 1908—the instantaneous rush of current at the moment of short circuit is equal to

$$\frac{\text{e. m. f.}}{\text{total impedance in circuit}}$$

About the time this was published, it was found from the oscillographic records that the value of the first few waves of current is dependent upon the phase of the voltage at the moment of short circuit, and that—as stated by Mr. Field—the first current wave can have a value approximately double that given by the above equation if the short circuit occurs at the instant when the e.m.f. is zero. It is not clear to me what Mr. Field means by "most probable" value of the initial short-circuit current, as it is the maximum possible value that we most protect against. For this reason, a short-circuit test on an a-c. generator is often of no value, as it may happen that the circuit is closed when the e.m.f. is a maximum, which would give the lowest value of the initial current rush. In practical operation, the generator might be thrown on the busbars with a bank of similar machines, 180 deg. out of phase, and at a time when the e.m.f. is zero. In such a case, the first rush of current would be four times as great, and the stresses on the end connection of the armature coils sixteen times as great, as those in the short-circuit test. As to the question of the capability of enduring the short circuit likely to be met with in practical operation, the purchaser is to a great extent dependent upon the manufacturer. Adequate tests are almost impossible to make and, in addition, are somewhat dangerous, especially in large vertical units, on account of the mechanical shock to the machine and the violent flashing and consequent burning of the rotor, due to heavy induced currents.

As Mr. Field points out, the modern tendency is to design large a-c. generators with high internal self-induction, and consequent poor regulation, in order to reduce the stresses on the generator and system generally caused by short circuits. A voltage regulator seems to have become a necessary adjunct of a modern power station, and since Mr. Stott has successfully overcome the difficulty of applying such regulators to a large system like the Interborough in New York, the day of closely regulated a-c. generators for power station work can now be considered as past.

The practise of using separate blowers and filtering the air through screens offers a number of advantages, but requires careful planning. The over-all efficiency, including friction, windage, and blower losses, may be very materially reduced with an external blower, unless the station is very carefully laid out; and unless the filter screens are cleaned frequently, they merely obstruct the air supply, or allow all the dirt to pass through. If the air supply to the screens and generator is at all dusty, it is practically impossible to avoid frequent cleaning of the air ducts in the machine.

I think that Mr. Field's valuable paper would be more complete if he emphasized that fact that the operating engineer and purchaser must depend to a great extent upon the ability and integrity of the manufacturer for the most suitable design for large high-speed units, as it is almost impossible to make specific tests which are of any practical value.

When the Cos Cob power station of the New York, New Haven and Hartford Railroad was first operated, five years ago, numerous short circuits on the 11,000-volt single-phase system were experienced; and this was probably the first occasion on which phenomena of high-power short circuits were urgently brought to the attention of engineers. A large number of experiments were carried out by Mr. Lamme and the writer which covered, to a great extent, the subject of the present paper by Messrs. Durgin and Whitehead. After Mr. Lamme had decided to install external reactance coils in the circuit of each generator (at that time quite an original idea), but before it was actually carried out, the operating engineers tried the effect of inserting a resistance in series with the generator—this being accomplished by connecting a feeder two miles (3.2 km.) long permanently in the circuit between the overhead line and the power house. The comparatively small resistance inserted had an extraordinarily good effect in reducing the shock of short circuits on the power house—so much so that it was even suggested that this resistance be left in circuit and the reactance coils not installed. These results started us investigating the relative value of resistance and reactance in limiting short circuits. Oscillographic records of the current obtained under different conditions were found to check with those determined theoretically from the following well known equation covering sudden changes in the impedance of a power circuit:

$$C = \frac{E}{\sqrt{R^2 + p^2L^2}} \sin \overline{p\,t - \omega}$$

$$+ E\left(\frac{\sin \overline{\theta - \alpha}}{\sqrt{\overline{R_0 + R}^2 + p^2\,\overline{L_0 + L}^2}} - \frac{\sin \overline{\theta - \omega}}{\sqrt{R^2 + p^2\,L^2}}\right)\epsilon^{\frac{R}{p\,L}(\theta - p\,t)}$$

Where

R_0 and L_0 are resistance and self-induction of circuit beyond the short circuit.

R and L are resistance and self-induction of generator and circuit inside of the short circuit.

$\omega = \tan^{-1}\frac{pL}{R}$ $\qquad \alpha = \tan^{-1}\frac{P\,(L + L_0)}{R + R_0}$

C = current $\qquad E$ = e.m.f.
θ = value of $p\,t$ at instant of short circuit
$p = 2\pi \times$ frequency $\qquad \epsilon$ = exponential
t = time measured from arbitrary zero

Curves similar to those shown in Figs. 8, 10 and 12 in Messrs. Durgin and Whitehead's paper, showing the beneficial results of the presence of resistance in circuit, were soon obtained—both theoretically and experimentally. The final decision to adopt choke coils rather than resistance to limit the short-circuit shock on any station was decided by the disadvantage caused by the waste of energy in the resistance. This is of interest historically as showing the steps that led up to the installation of choke coils at Cos Cob, which set a precedent for what has now become standard practise in almost all new large power stations.

This paper is an extremely useful and complete explanation of the general phenomena of the a-c. generator short circuits and is especially valuable as being based upon a complete series of tests under practical operating conditions. The author's remarks in reference to " transient reactance " in an a-c. generator bring to mind the discussions that have taken place during the past twenty years involving the question of the self-induction of an alternator. Those who have followed these discussions know what was, I think, first pointed out fifteen years ago by M. Blondel, that the term " self-induction of an alternator " is a meaningless expression until a definition is given of exactly what is meant. The e.m.f. of self-induction in any electrical circuit is the e.m.f. caused by the time rate of change of the lines of force linking with the circuit, and due to the current in that circuit.

In any alternator, this is an extremely complicated phenomenon. The self-induction varies with the reluctance of the magnetic circuit, which again varies with the relative position of the iron and electric circuits of the field magnets and armature; and also depends on the permeability of each part of the iron circuit, which again varies with the value of the current. The fact that the "transient reactance," as found by experiments, appeared to be only 28 per cent of that calculated by the authors, is not surprising, and only emphasizes the necessity of depending upon experiments and actual tests, rather than upon calculations based necessarily upon assumptions.

SECTION II

PROCEEDINGS

of the

American Institute

of

Electrical Engineers

Papers, Discussions and Reports

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TEMPERATURE AND ELECTRICAL INSULATION

BY

C. P. STEINMETZ and B. G. LAMME

(Sub-committee on Revision of Rules.)

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TEMPERATURE AND ELECTRICAL INSULATION

BY. C. P. STEINMETZ AND B. G. LAMME

The problem of permissible temperature limits in electric apparatus is largely that of the durability of the insulation used. As this may consist of materials of widely varying heat-resisting qualities, the problem resolves itself into one of consideration of the properties of the materials themselves.

The durability of insulation may be considered from two standpoints, the mechanical and the electrical. Tests and experience have shown that temperatures which may ruin the insulation, from a mechanical standpoint, may not radically effect its dielectric strength. This is particularly true with moderate voltages where the insulation serves largely as a separating medium. The purpose of the insulation usually is two-fold: First, it must serve to separate, mechanically, the electric conductors from each other, and from other conducting structures, and second, it must withstand the voltage between the electric conductors and between the electric circuits, and other conducting parts. In lower voltage apparatus, usually only the former function applies, as the mechanical separation is more than sufficient to withstand the voltage used. The dielectric strength of the material is, however, of first importance in high voltage apparatus.

A great majority of the electrical "breakdowns" on low voltage apparatus is due to mechanical weaknesses, as far as the temperature problem is concerned; that is, high temperatures may make the insulation brittle, or crisp, so that it may flake off, or powder, or crack, or be crushed by mechanical action, thus allowing the conductors to make contact with each other or with adjacent conducting material.

The "life of insulation" is an indefinite term and must be defined in time, mechanical strength, absence of foreign materials of a conducting nature, etc. Almost all insulating materials will be somewhat affected in time, and many of them tend to become dry and brittle. The rate at which deterioration occurs with any given material, is some complex function of the temperature and of other conditions.

CLASSES OF INSULATIONS

Insulations may be classified under three headings, depending upon their heat-resisting properties. However, all such classifications must be relative, for no absolute limit can be fixed, as there is no definite point at which injury or destruction can be said to take place.

The usual insulating materials can be considered as included in three general classes:

Class A. This includes most of the fibrous materials, as paper, cotton, etc., most of the natural oil resins and gums, etc. As a rule, such materials become dry and brittle, or lose their fibrous strength under long continued moderately high temperature, or under very high temperature for a short time.

Class B. This includes what may be designated as heat-resisting materials, which consist of mica, asbestos, or equivalent refractory materials, frequently used in combination with other supporting or binding materials, the deterioration of which, by heat, will not interfere with the insulating properties of the final product. However, where such supporting or binding materials are in such quantity, or of such nature, that their deterioration by heat will greatly impair the final product, the material should be considered as belonging to class A.

Class C. This is represented by fireproof, or heat-proof materials, such as mica, so assembled that very high temperatures do not produce rapid deterioration. Such materials are used in rheostats and in the heating elements of heating appliances, etc.

All the above are relative terms. The first class, for instance, represents materials which are really more or less heat-resisting, but which deteriorate at lower temperatures than those in the second class, which are defined as heat-resisting. Also, the fireproof materials of the third class are not strictly heat-proof or fireproof, but will simply withstand very high temperatures for relatively long periods without undue deterioration.

In class A, the materials appear to have a very long life (or an almost indefinitely long life, aside from mechanical conditions) if subjected to ultimate temperatures which never exceed 90 deg. cent. Also, they appear to have a comparatively long life, even at ultimate temperatures as high as 100 deg. cent. At materially higher temperatures than 100-deg. cent., the life is very greatly shortened, and temperatures of 125 deg. cent. will apparently ruin the insulation, from a mechanical standpoint, in possibly a few weeks, if such temperature is maintained steadily. However, for low voltages, the insulating qualities may still be very satisfactory, even at this temperature, and therefore the destruction of the insulation is purely one of injury or breakdown from the mechanical standpoint, as stated before. Temperatures as high as 160 deg. cent. on such insulations for a considerable period may not entirely destroy their insulating qualities, although, mechanically, such temperatures appear to be impracticable, except for very short periods.

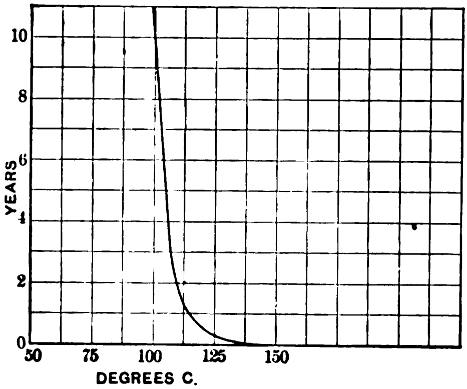

FIG. 1

In order to illustrate the relation between the possible life and temperature of class A insulation, Fig. 1 is shown. This must not be taken as representing actual results, but is simply intended to illustrate, in a very approximate manner, the very great shortening of the life of insulation by increase in temperature.

It may be assumed that at very high temperatures, the insulation will have practically the same life, in actual hours of high temperature operation, whether the temperature is applied continuously or intermittently. For example, if an insulation has 10,000 hours life with a certain high temperature continuously applied, it is assumed that it will also stand the same temperature for 10,000 hours in short periods, provided the intermediate temperatures are low enough to represent an indefinitely long life. It is probable that under the intermittent condition, the life will really be slightly greater, due to the fact that depreciation will be largely mechanical, and the insulation may "recover," in some of its mechanical characteristics after each period of high heating.

If, therefore, high temperatures are reached intermittently, with intermediate periods of lower value but still high enough to shorten the life of the insulation, it may be assumed that the total life of the insulation is the resultant of the life under the two temperature conditions.

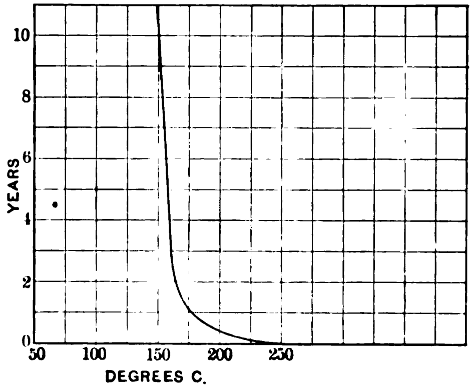

FIG. 2

In heat-resisting materials, such as those of class B, temperatures of 125 deg cent. are comparable with 85 deg. cent. or 90 deg. cent. in class A, and 150 deg. cent. in the former is comparable with 100 deg. cent. in the latter. Fig. 2 illustrates very approximately the life-temperature curve of such insulations. As in Fig. 1, this should not be taken as an exact representation of the actual life. Due to the greater heat-resisting qualities of such materials, it appears that relatively higher temperatures are not as quickly harmful as in the first class.

In class C materials, it is difficult to give any reasonable indication as to the limits of temperature, except that very high temperatures, (practically up to the point of incandescence) are found in some heating appliances.

TEMPERATURES AND FLOW OF HEAT

As the insulation, in itself, is not usually the seat of generation of loss or heat, it is the temperature of adjacent materials which must be considered in defining the conditions in the insulation. The temperatures of the adjacent materials should therefore be considered only in so far as they affect the insulation itself, and where such temperatures do not affect the insulation, or the life of the apparatus, or its normal perfomance, they are immaterial.

Considering the influence of the temperatures of the adjacent media, the direction and amount of heat flow must be taken into account, as the maximum temperature in the insulation is dependent upon these. In the case of armature windings, for instance, the heat flow may be from the buried portion of the coils toward the end windings. It also may be from the buried copper through the insulation to the armature teeth, or there may be a reverse heat flow from the iron to the copper, depending upon the various factors of construction, heat conductivity of the materials, amount of heat generated in the various parts, ventilation, heat dissipation etc.

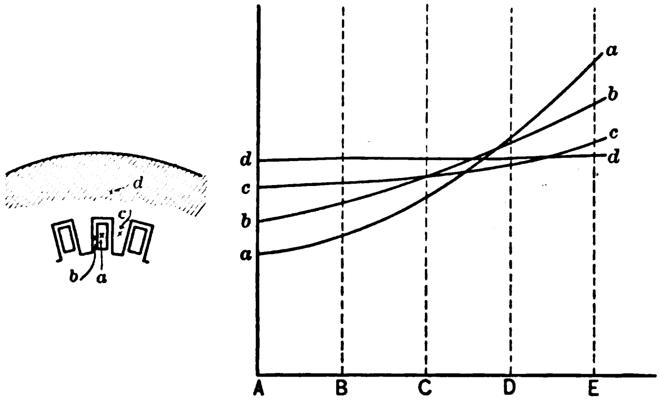

FIG. 3

Depending upon conditions of heat flow and distribution, various methods of temperature determination may be used. No method is accurate, unless all the conditions of heat flow are accurately known, which is never the case in commercial machines.

The difficulties in the problem of commercial temperature determination are illustrated by Fig. 3.

In the figure, *a* represents the temperature inside an armature coil, *b* the temperature between the insulation and the iron of an armature tooth, *c* that in the body of the tooth, and *d* that in the body of the core at some point back of the coils and teeth. Let the temperatures at no load be represented on the ordinate *A*. Then, at some load, represented by ordinate *B*, the relations of the various temperatures have changed. At *C*, *D* and *E*, there are still greater changes, depending upon the heat generation and distribution. If the rated capacity of the machine is at *E*, for instance, then the armature copper is hotter than the iron, while if rated at *B*, the reverse would be true. Obviously, no rule can be formulated to cover these various conditions in different machines, nor even in a given machine, unless all the heat generation, distribution, and dissipation characteristics are known. Obviously, as far as the insulation is concerned, the temperatures of *a* and *b* are the only ones which need be considered.

All temperature determinations of a commercial nature, are necessarily approximations, or relative indications, upon which proper margins must be allowed for the ultimate temperature possibly attained. Therefore, in apparatus where there are liable to be discrepancies of 10 deg. between the measurable and the actual ultimate temperatures, a limit of 90 deg. cent. should be allowed by conventional temperature measurement on insulations in which 100 deg. is set as the maximum temperature with a reasonable length of life.

The conventional methods of temperature measurement, as by resistance, and by thermometer, do not usually give the maximum temperature, but give either the average, or the outside surface, values, and, when measuring the temperature by these methods, which are the only ones generally applicable, an allowance must be made in windings for possible local higher temperatures. These methods apply especially to those machines of moderate or low voltages in which the insulation is relatively thin, so that the heat gradient from the inside copper to the outside surface is small. Also, they apply particularly to those machines in which the conditions of ventilation are not normally difficult, and in which a fairly thorough distribution and dissipation of heat occurs among the various parts, such as in ordinary direct-current armatures, induction motors primaries, stators and rotors of moderate speed alternators in which the width is relatively small compared with the diameter, etc.

As the ultimate temperatures obtained by the apparatus depend upon its rise above the room temperature, or that of the cooling medium, and as such temperatures may vary over a wide range, it is not practicable to specify or guarantee ultimate temperature of apparatus without also specifying the elements upon which it depends. This, therefore, results in specifying the temperature rise in relation to that of the cooling medium.

While most apparatus operates at materially lower cooling temperature than 35 deg. cent. to 40 deg. cent., yet such temperatures are sometimes reached for considerable periods of time in steam stations, and it appears therefore as justifiable to choose the permissible temperature rise, such that, at room temperature of 35 deg. cent. to 40 deg. cent., an ultimate temperature of 85 deg. cent. to 90 deg. cent. by conventional methods of measurement, is not exceeded. This means, therefore, a temperature rise of 50 deg. cent. with conventional methods of testing, such as by increase of resistance, or by thermometer, in those insulations which can stand a continuous ultimate temperature of 100 deg. cent. with a comparatively long life. This allows an excess of 10 deg. cent. to 15 deg. cent. for local spots, or for the temperature gradient through the insulation. A less allowance should be made for this difference when methods of temperature measurement other than the conventional are used, and which approach more closely to the highest temperature actually attained.

When the above temperatures are liable to be materially exceeded for long periods, heat-resisting insulation of class B is recommended. With such materials, a temperature of 125 deg. cent. is comparable with 85 deg. cent. to 90 deg. cent. in the materials of class A. Therefore, on this basis of a room temperature at 40 deg. cent. or 45 deg. cent., rises of 85 deg. cent or 80 deg. cent. should not be considered harmful. However, in those special cases where the conventional methods may not sufficiently approximate local high temperatures, as may be the case in large turbo-generators, or in wide core alternators of large capacity, the rises of 80 deg. cent. or 85 deg. cent. should not be specified by resistance or thermometer, but preferably some lower temperature such as 50 deg. cent. thus allowing a very considerable margin for local higher temperatures. In such apparatus with the higher temperatures, which require class B insulation, there is liable to be less uniformity of heat distribution.

If special methods of temperature measurement, such as exploring coils or thermo-couples are used in such apparatus, the temperature limit of 125 deg. cent. should be considered, and not the conventional 50 deg. cent. rise. In those machines of this class which have relatively thick insulation, and consequently may have a high heat gradient between the copper and the iron, (depending upon how much heat is flowing from the copper to the iron) an ultimate temperature of the inside insulation of 150 deg. cent. is considered as the limit, this being comparable with 100 deg. cent. with insulations of class A.

In certain classes of apparatus which are artificially cooled by air from outside the room, the cooling is accomplished partly by dissipating heat to the artificial air supply, and partly by dissipation into the surrounding room. If the temperatures of the cooling air and of the room are widely different, the resultant of the two temperatures should really be taken as that of the cooling medium.

The variation of the temperature rise has heretofore been considered as having a definite relation to the temperature of the cooling medium. However, it appears that it does not follow any definite simple law, but it is sometimes positive and sometimes negative, so that no satisfactory correction for room temperature is possible at present. It is therefore desirable to make the temperature tests at a room temperature as nearly as possible to some specified reference temperature, so as to make any temperature correction negligible. The reference temperature in the guarantees should therefore be such as can easily be secured; that is, it should be the average temperature of the places at which the apparatus may be operated. This is from 20 deg. cent. to 25 deg. cent., and as it is easier to raise than to lower the room temperature, the upper figure is advisable as a reference value. This reference temperature therefore should be chosen as 25 deg. cent.,which is in accordance with the previous A. I.E.E. standard.

MEASUREMENT OF TEMPERATURE

In the conventional methods of temperature measurement, by thermometer, and by resistance, many conditions should be taken into account, and good judgment is required, in all cases, or fallacious conclusions may be obtained.

There are many conditions which affect both the accuracy of the resistance and the thermometer methods of measuring temperature. The resistance method measures only the average temperature rise, and not that of local hot spots. However, it measures the internal temperature of windings, and therefore no correction is required for the temperature gradient through the outside insulation. The proposed margin between the result by the conventional method, and the actual temperature can therefore be allowed, in the resistance measurement, as the difference between the warmer and the average temperatures in the windings. In the resistance method of measurements, the rate of transfer of heat from one part of the winding to another will not greatly affect the result, as the measurement indicates an average temperature, which is that obtained if the heat were equalized throughout the winding. However, the rate of flow of heat from the windings through the outer insulation to other parts, will affect the temperature measurement by resistance, and preferably the measurement by this method should be taken during operation in those parts where this is practicable, as in field coils, and some other instances. In those parts where the resistance cannot be measured during operation, this should be done as quickly as possible after shut-down, and the time taken to shut down the apparatus should not be unduly long. Preferably, during shut-down of rotating apparatus the normal current should be maintained on the apparatus until at least a relatively low speed is obtained. This would represent only an average condition, as the ventilation at lower speed is very greatly decreased, while the losses in the windings will remain normal, thus tending to give an increased temperature in the windings. It would be difficult to fix any definite rule which would give the exact temperature conditions during shut-down.

In the measurement of temperature by thermometer, considerable judgment is required. Wherever possible, the temperature should be taken during operation, but the thermometer with its pad should be so placed that it does not interfere with the normal air circulation. In thermometer readings, as usually obtained on windings, the heat gradient through the insulation must usually be allowed for, this being 10 deg. to 15 deg. as previously defined. However, depending upon the method of taking the temperatures, this allowance should vary over a considerable range, depending upon whether or not the method of measurement approximates the actual internal temperature. For instance, the total heat gradient from the inside copper to the outside air will be that through the coil insulation, plus the thick covering pad over the temperature bulb. If the gradient through the covering pad is very large compared with that through the insulation, the thermometer may indicate almost exactly the internal temperature of the copper; that is, the heat gradient through the insulation to the thermometer, may be relatively small compared with the total gradient to the air. This is particularly true where the thermometer rests on a metallic seat which covers a considerable portion of the coil surface. In this case, the heat which affects the thermometer bulb will pass through a relatively large section of surface, with a correspondingly small drop in temperature, so that the bulb more closely approximates the temperature of the inside copper.

Where there is local heating in the windings, and a consequent liability of rapid transference of heat to other parts, the results obtained by the thermometer method will vary to some extent with the rapidity with which the actual measurement is made; that is, the more quickly the thermometer can be brought up to the full temperature, the more accurately the temperature of the hottest part is determined. With a very rapid method of measurement, it may be possible to measure practically the internal temperature of the copper of the winding before any great heat transference or dissipation has occurred. In such cases, obviously, the full allowance for the usual temperature margin should not hold. It should be fully understood that it is the ultimate temperature, and not the temperature rise, which should be considered as the limiting condition, and that the measured rise, plus the allowances for temperature gradient, plus the measured room temperature, is simply an indication of the possible ultimate temperature. By whatever method the temperature measurement is made, in all cases the results may be considered as more or less approximate, and in the end, it is the manufacturer who must supply the necessary margin over the approximate measurement, in order to make the machine safe.

A blind adherence to some particular rule or method of taking temperatures, may lead to fallacious results in some instances. In armature windings, in particular, incorrect readings may be obtained after shut-down. For example, if the armature iron back of the armature teeth were hotter than the armature teeth and coils during operation, then the temperature to which the insulation is subject during operation may be considerably lower than that in the hottest part of the machine, due to the ventilation conditions when running. However, upon shut-down, the temperature at the insulation may rise to that of the hottest part of the machine, and therefore a false temperature, by any method of measurement, might be indicated.

RECOMMENDATIONS

That with class A insulation, 90 deg. cent. be taken as the ultimate temperature limit, as indicated by conventional methods of measurement, or those which give similar results, and that 100 deg. cent. be considered as the maximum ultimate temperature permissible in the insulation, where a comparatively long life is a requirement.

That 40 deg. cent. be taken as the limiting temperature of the cooling medium, or room, and that, therefore, 50 deg. cent. be the permissible rise by conventional methods of measurement, with class A insulation.

That 25 deg. cent. be taken as the reference air temperature. With the permissible 50 deg. cent. rise, this gives 75 deg. cent. as the average operating condition, by conventional methods of measurement, or 85 deg. cent. actual temperature, when the usual margin represented by the temperature gradient is added.

An exception to the rise of 50 deg. cent. can be made in those cases where space or weight limitations are such that higher temperatures, with consequent reduced life, are commercially economical, such as in railway motors. In such cases, with class A insulation, a rise of 65 deg. cent. with reference air at 25 deg. cent. is at present accepted as good practice.

With class B insulations, 125 deg. cent. be taken as the ultimate temperature limit, as indicated by conventional methods of measurement, or by equivalent methods, and 150 deg. cent. be considered as the maximum ultimate temperature permissible in the insulation. It follows therefore that 80 deg. cent. to 85 deg. cent. rise is allowable, with such insulations, by the usual methods of measurement.

No temperature correction should be made for variation of the cooling temperatures from the reference temperature of 25 deg. cent.

When the method of temperature measurement shows the highest temperature actually obtained in the insulation, the maximum temperatures specified for the given type of insulation should hold.

In the final decision on questions of temperature rise, the ultimate temperature should be the basis, rather than the rise.

METHOD OF RATING ELECTRICAL APPARATUS

BY

W. L. MERRILL, W. H. POWELL and CHARLES ROBBINS
(Sub-committee on Rating)

Presented under the auspices of the

Standards Committee

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METHOD OF RATING ELECTRICAL APPARATUS

BY W. L. MERRILL, W. H. POWELL AND CHARLES ROBBINS

An investigation, covering the past three years by the subcommittee on the subject of Rating Electrical Machinery, has shown conclusively that the present Standardization Rules of the American Institute of Electrical Engineers have, in many respects, become inconsistent as well as inadequate to meet the present service conditions which electrical apparatus is called upon to fulfill.

A comprehensive study of the subject has led us to believe that the rules representing fundamental methods of rating could be formulated. Such rules should not only meet existing conditions but also provide such flexibility as is necessary when limitations, due to existing materials, are changed by the future progress of the art.

It is highly desirable that the rating of electrical apparatus should be accurately defined and placed upon such a basis that it can be adopted internationally, since it is obvious that the service requirements in other countries are substantially the same as those in the United States.

This subject has been considered at considerable length by the International Electrotechnical Commission and an analysis of the work done by it leads us to believe that an international standard of rating is not only possible but essential. This is very desirable in view of the fact that the influence of the A. I. E. E. is recognized in the United States, Canada and Mexico.

The suggestions herewith submitted are based upon the accumulated data prepared after an analysis of service conditions, and represent the fundamental limits which should be considered in the rating of electrical apparatus, and it is believed that further investigation and the discussions on service conditions will substantiate the conclusions herein presented.

CAPACITY RATING

Item 1. *All electrical apparatus should be rated by output.*

Item 2. *Apparatus which delivers electrical power*:

Apparatus of this class should be rated in kv-a. or in kw. where the kv-a. and kw. are equal:

a. Therefore, direct current generating apparatus should be rated in kw.

b. Therefore, alternating current generating apparatus should be rated in kv-a. at a definite power factor which must always be specified, if not inherent in the apparatus, (as for instance is the case in the induction generator.)

Item 3. *Apparatus which transforms from electrical power to to electrical power*:

Apparatus of this class should be rated in kv-a. or kw. in exactly the same manner as in item 2.

Item 4. *Apparatus transforming from electrical to both electrical and mechanical power*:

Apparatus of this class should be rated in kv-a. or kw., which represents the resultant of mechanical and electrical outputs, the two components being specified.

Item 5. *Apparatus which transforms electrical to mechanical power.*

Since the input in apparatus of this class is measured in electrical units, and the output has a direct relation thereto, it is logical and desirable to measure the delivered power in the same units, Therefore the output of motors should be rated in kilowatts.

On account of the predominant practise of rating mechanical power in h.p. it is suggested that apparatus of this class for the present be given a double rating, *i.e.*,

kw.................... h.p..................

SERVICE RATINGS

An analysis of the service conditions that electrical apparatus is called upon to meet, leads us to recommend that ratings be divided into two general classifications, based upon the length of time of service the apparatus is in operation.

These two general classifications will again divide into three sub-classifications depending upon the character of the load conditions.

Continuous Rating. (A) In which under specified conditions of operation there is an attainment of approximately stationary temperatures, and no other limit of capacity is exceeded. This may be sub-divided into the following classes:

(A-1) Constant service—where the load is continuously applied.

(A-2) Continued periodic service—in which the service consists of alternate conditions of load and rest, the periods of which must be specified.

(A-3) Continued pulsating service—in which the service consists of conditions of load and partial load, the magnitude and duration of which must be specified.

Short Time Rating. (B) In which under specified conditions of operating, stationary temperature is not reached, and no other limit of capacity is exceeded.

(B-1) Short time constant—where the load is continuously applied for a specified period.

(B-2) Short time periodic—in which the service consists of alternate conditions of load and rest, the periods of which must be specified.

(B-3) Short time pulsating—in which the service consists of conditions of load and partial load, the magnitude and conditions of which must be specified.

TEMPERATURE OF ELECTRICAL APPARATUS

As the ultimate temperature is the sum of the temperature of the surrounding cooling medium and the rise of temperature due to the load conditions imposed upon the apparatus, it is necessary to take into account the variations encountered in the cooling medium. The cooling medium will vary in different places, depending upon geographical location of the apparatus; upon the season of the year, and the housing of the apparatus. Under this latter condition, it is found that the cooling medium may vary very widely in temperature, and may, in poorly ventilated places, and in locations influenced by other conditions, run as high as 40 deg. cent. even though the outdoor temperature may be lower.

It is believed that the average temperature of the cooling medium in which electrical apparatus is operated in practise and in which they should be tested, is about 25 deg. cent.

It is therefore recommended that the standard temperature of the cooling medium be chosen as 25 deg. cent., and that all measurements and tests of electrical apparatus be based on a room temperature of 25 deg. cent.

Since, however, the life of the insulating material depends on the ultimate temperature attained and this depends on the temperature of the cooling medium, it is necessary to recognize the fact that apparatus is frequently operated in locations where the cooling medium may have a range of temperature much higher than 25 deg. cent. It is recommended that 40 deg. be recognized as the upper normal limit of the cooling medium and that temperatures higher than 40 deg. should be accepted as abnormal conditions and require special consideration.

TEMPERATURE OF APPARATUS

1. Ultimate Temperature:

a. Cotton, treated cloth, paper, and similar substances which may fall in this general classification, a maximum ultimate temperature of 90 deg. cent.

b. Heat resisting materials such as asbestos and mica compounds, etc., a maximum ultimate temperature of 125 deg. cent. Insulating material should be considered as belonging to class (b) even if containing material of class (a), provided that class (a) material is used only as a means of facilitating construction and may be entirely destroyed without interfering with the functions of the insulation. In this case the ultimate temperature is that of class (b).

c. Fireproof materials such as pure mica, porcelain, etc. No temperature limit can be specified.

These recommendations do not apply to apparatus or parts thereof, the principal function of which is the generation of or dissipation of heat, (such as rheostats and heating devices) and to structures and materials which are not damaged by heat.

2. Temperature to be determined by approved method as may be specified in A. I. E. E Rules.

3. Under the stipulated load conditions, the following temperature rises on windings are recommended:

CONTINUOUS SERVICE	
Class " a " insulation	50 deg.
Class " b " insulation	85 deg.

SHORT TIME SERVICE	
Class " a " insulation	55 deg.
Railway motors, class " a " insulation	65 deg.
Class " b " insulation	90 deg.

Short time temperature rises may be on a slightly higher basis, *i.e.* five deg. as indicated in the foregoing table, because the fluctuating load will permit of substantially the same life, in years, when operating intermittently under slightly higher temperature.

It is recognized that railway motors require special consideration, owing to the relatively larger power required in a confined space, and that therefore a higher temperature rise must be permitted, and that the life of the insulation under operating conditions will be materially less than for the other classes of service.

As railway motors operate under good conditions of external ventilation when carrying load, the temperature rise of 65 deg. is permissible.

Commutators. The heating of a commutator is due to several causes:

a. Conduction of current in the bars.
b. Conduction of heat from the armature structure.
c. Conduction of heat from the bearings.
d. Heating due to brush friction.
e. I^2R loss between the commutator and the brush.

This heating has no material effect upon the life of the insulation between the commutator bars, except that mechanical distortion may take place. The effect of the heating may, when excessive, cause deterioration of the commutator due to the distortion of the bars, but if the structure is so designed that ***harmful*** distortion cannot take place, the heating limits of the commutator should be that of the winding to which it is connected, *i.e.*, 50 deg. cent. for class (a) insulation, except, in those instances where class (a) insulation, may have a permissible rise of 55 or 65 deg., or 85 or 90 deg. for class (b) insulation.

Other Material. The temperature rise of any part of the apparatus which is in contact with insulation must not be greater than that allowed for the insulation with which it comes in contact.

A higher temperature than that specified is permissible for such parts of the apparatus as do not come in contact with the insulation and therefore cannot, by their higher temperature, deteriorate the insulation.

Bearings. It is recommended that bearings should fall into the general classification of " Other Material " of the machine not in contact with insulation, and may have any temperature that will permit of safe and successful operation.

SERVICE RATINGS

It is recommended that continuously rated electrical apparatus falling within class (A-1) be rated upon a basis of ultimate temperature without other limits of capacity being exceeded, and it is further recommended that no overloads be specified for apparatus except momentary overloads. Momentary overloads are defined as not exceeding sixty seconds, and should be as follows:

The maximum running torque of motors should not be less than 150 per cent normal rated torque.

Commutating apparatus should commutate not less than 150 per cent of the rated current.

Alternating-current machines should carry momentarily not less than 150 per cent rated current without regard to the rated voltage.

Motor Generators. Generators should have the same overload requirements as designated under " Generators." The motors to have sufficient capacity and overload reserve to drive the generator.

Mechanical Service Conditions. All types of rotating machines should be so constructed that they will operate with safety at an overspeed of 25 per cent above the maximum rated speed, except in the case of steam turbine which when equipped with emergency governors should be constructed for 20 per cent over the maximum rated speed, and in the case of series motors no overspeed can be recommended on account of the varying service conditions.

Water-wheel generators should be constructed for the maximum runaway speed which can be reached by the combined unit under service conditions.

For a large percentage of apparatus which falls within classes (A-2) and (A-3,) and (B-1), (B-2) and (B-3), other limitations prevail. These types of electrical apparatus are designed to meet definite service conditions demanding selection of apparatus having a rating which will meet the exact operating specifications. These limitations are fundamental to the design, and it is therefore desirable that a definite commutation limit, a prescribed starting torque, a prescribed pull out torque for a-c. motors, with a definite factor of safety for mechanical construction, be the limiting factors of the rating.

APPENDIX

CAPACITY RATING

Item 1. All electrical apparatus should be rated by output.

Item 2. In the case of alternating current generators, the kilovolt-ampere is a much more logical unit than the kilowatt, since the capacity of such machines when expressed in kilovolt amperes is generally independent of the power factor, and in any case is much more nearly independent of power factor than when the rating is given in kilowatts. However, in the case of machines in which the field limits the capacity, the allowable kilovolt-ampere rating varies considerably with the power factor and hence power factor should be specified in all cases.

Item 3. In the case of stationary transformers, the rating in kilovolt-amperes is almost entirely independent of power factor, hence this method is the only logical one in this case. For synchronous converters, the rating depends both upon the power factor at the a-c. end and the direct-current load. Hence, both should be specified. For frequency changers and motor generator sets, the same conditions obtain as in Item 2.

Item 4. Thus a synchronous converter which delivers both mechanical power and electrical power should be rated as kilowatt mechanical power and kilowatt (or kilovolt-ampere at a particular power factor) electrical output. If it is used partly as a synchronous condenser as well, for power factor correction, the a-c. power factor should be specified.

Synchronous condensers, for power factor correction only, should be rated in kilovolt-amperes at zero power factor. When a machine of this type is operating as a synchronous condenser, the power factor will not be quite zero, since losses are supplied electrically, but the difference will generally be too small to consider.

Item 5. From the pure science standpoint, the kilowatt is a better unit of power than the horse power since it is based directly upon the absolute c.g.s. system, the watt being equal to 10^7 dyne-centimeters per sec., while if we accept the definition of the horse power as being 550 ft-lb. per sec., it is a gravitational unit and so is not strictly constant, but varies slightly with the latitude.

Also the kilowatt is the practically universal unit for the measurement of electrical power throughout the civilized world, while the " horse power " beside varying on account of its being a gravitational unit is defined differently in different countries. In several European countries it is defined as 75 kg-m. per sec., while here it is 550 ft.-lb. per sec. The difference is about 1½ per cent.

Then too there seems to be no real reason why both electrical and mechanical power should not be expressed in the same units, and since the kilowatt is much more desirable as a universal unit than the horse power for the reasons enumerated, it is recommended that the output of motors be expressed in kilowatts instead of horse power.

In the case of synchronous motors which are also used for power factor correction, the power factor at the motor terminals should also be given (leading power factor being understood) unless otherwise specified.

Name Plate Stamping

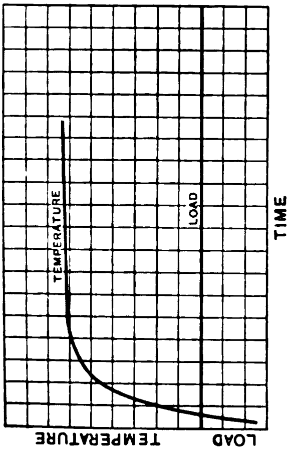
It is evident for ratings (A-2) and (A-3), (B-1), (B-2) and (B-3), that certain stand tests or compromise runs of machinery, and particularly motors, are desirable. These stand tests in addition to determining various characteristics of the apparatus, should also determine as a basis of comparison the heating of the machines, and as the machinery is selected for various and sundry cycles of operation, two methods can be recognized for stand tests.

One is, in the case of class (a) machinery where the machine is run until it reaches a constant temperature under conditions where the losses and windage would be the same as the normal rating of the machine. This, however, in many cases might prove difficult, and a stand test made in accordance with a (B-1) rating could properly be substituted, as is now done in case of crane motors, machine tool motors, railway motors, etc., where the stand test may or may not be the same as the rating of the machine.

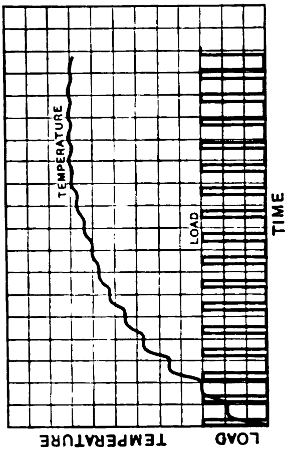
The present method of rating machinery on the so-called intermittent basis, is somewhat confusing, as for example; a motor rated " 10 h.p.—two hours intermittent," really means that the motor will perform certain cycles of operation, the equivalent stand test of which is two hours of continuous running at 10 h.p. This is often interpreted to mean that the motor when installed will have to be shut down after two hours of operation or the motor will be injured.

It is suggested that a system of name plate stamping be adopted which will designate the apparatus according to the various classifications set forth in this paper, and that in addition to the ordinary information given on the name plates, the equivalent stand test be included.

The following load and temperature curves indicate the nature of the six ratings as recommended by the sub-committee on rating.



A1



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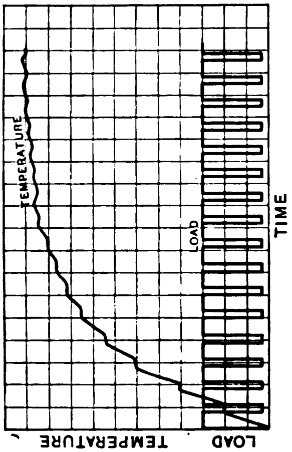

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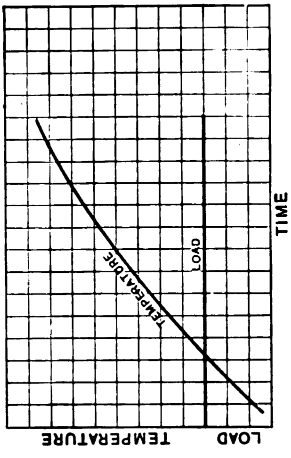
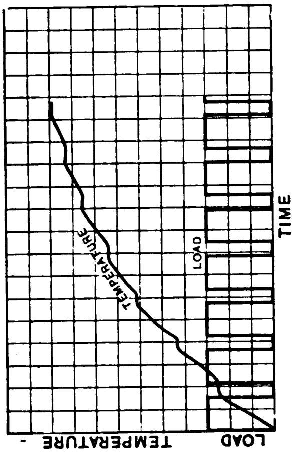
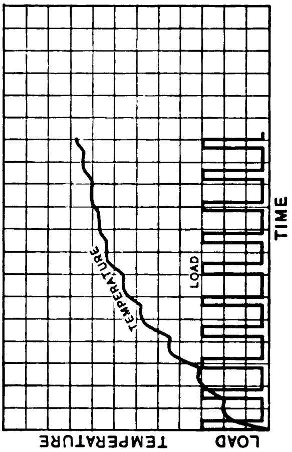


B1

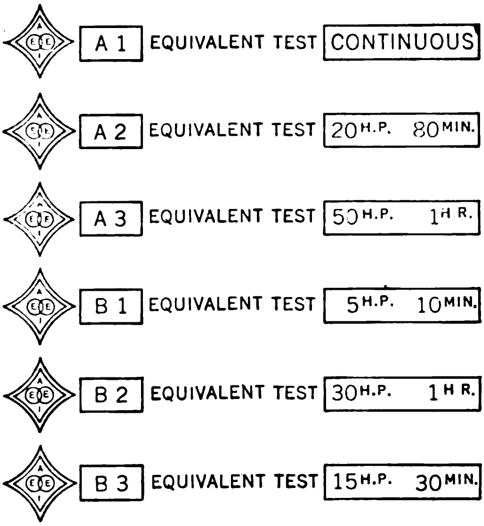


B2



B3

It is also recommended that the name plates of all machinery rated in accordance with the future rules of the Institute bear the inscription of the A. I. E. E., as suggested in the following examples.


A 1 EQUIVALENT TEST CONTINUOUS
A 2 EQUIVALENT TEST 20 H.P. 80 MIN.
A 3 EQUIVALENT TEST 50 H.P. 1 H R.
B 1 EQUIVALENT TEST 5 H.P. 10 MIN.
B 2 EQUIVALENT TEST 30 H.P. 1 H R.
B 3 EQUIVALENT TEST 15 H.P. 30 MIN.

INDUCTION MOTOR LOAD LOSSES

BY

HENRY G. REIST and A. E. AVERRETT

Presented under the auspices of the

Standards Committee

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INDUCTION MOTOR LOAD LOSSES

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ABSTRACT OF PAPER

On account of uncertainties and irregularities, methods of measuring losses are more desirable than those involving the entire energy.

The usual losses, *viz.* core, loss, friction, and I^2r are mentioned and conditions shown under which so-called load losses appear; these are largely in the form of excess core loss, due to saturation of the teeth. Excess copper loss may also appear and be corrected for, both in primary and secondary.

Test results are given showing the effect of saturation in the teeth, and excess copper losses; also from 29 input output tests, showing the efficiency by direct measurements in comparison with the method of losses, showing an average of about ¾ of 1 per cent lower by direct measurement.

Results of two tests are shown where load losses were excessive, due to peculiar construction.

The conclusion is that where no saturation exists there will be no load losses, and no excess copper losses in wire wound stators.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26–28, 1913.

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(*Subject to final revision for the Transactions*.)

INDUCTION MOTOR LOAD LOSSES

BY HENRY G. REIST AND A. E. AVERRETT

The question of load losses on induction motors frequently comes up when the various methods of testing are discussed.

It is usually more desirable to measure the losses and thus obtain indirectly the efficiency, than to obtain it from a direct input and output test, because a variation of two or three per cent in the losses will affect the efficiency results only slightly, while on direct measurement the error would be large.

Commercial circuits are, as a rule, more or less unsteady, both voltage and frequency changing dependent upon the load; as both efficiency and power factor largely depend on the constancy of conditions, it is desirable to eliminate methods which require laboratory conditions to insure accuracy.

On large machines it is almost impossible to take direct measurements on account of limited power. Therefore, some method of determining the efficiency by losses is imperative.

The losses usually measured are core losses, friction, and windage, primary and secondary I^2R losses. See A. I. E. E. Standardization Rules, sections 162-167. Core loss is usually nearly constant, but under certain conditions may increase with the load and materially reduce the efficiency.

The customary method of obtaining the core losses is to run the machine without belt at gradually reduced voltage until it breaks down, reading both watts and amperes; curves of these values are plotted, and the point where the watt curve extended passes through the ordinate at zero voltage is taken as friction.

The I^2R at normal voltage is subtracted and the remainder is taken as core loss.

Primary I^2R is directly obtainable; the secondary, when of a definite phase wound type, is also directly secured, but when a squirrel cage type must be obtained by indirect methods, and is approximately proportional to the slip.

LOAD LOSSES

Under certain conditions the core loss and I^2R are materially increased.

When the saturation occurs in the iron, due to the load current, the core loss may be increased on account of a changed flux distribution. This is especially noticeable in motors with completely closed slots, that is, with a thin iron bridge across what would normally be the slot opening.

Such motors do not have a constant reactance or core loss, but both change with load, due to the saturation in the thin iron parts—the core loss increasing and the reactance decreasing. Under these conditions the only correct method of obtaining the efficiency is by an input-output test. The amperes at short circuit, with the rotor blocked, increase more rapidly than the voltage, whereas a motor without saturation will show amperes proportional to the voltage.

Nearly all motors, however, will show some saturation in the blocked condition when several times full load current passes, and a constant core loss should be assumed only through the range of short circuited current where the amperes are proportional to the voltage.

COPPER LOSSES

The copper losses are also subject to correction. Eddy currents will appear wherever heavy conductors are used. These eddy losses are shown by the wattmeter readings taken with the rotor blocked. Those chargeable to the stator are additional to the primary I^2R from measured resistance; those belonging to the rotor or secondary practically dissappear under load conditions due to the low frequency of slip.

In order to separate these the rotor can be removed and a stator test made with amperes and watts; if there are no eddies the I^2R and measured watts will agree, but if not the excess watts will represent additional losses which appear under load, and can be represented by an effective resistance.

Tests have been made which verify the above statements; round wire or rectangular strip of one cm. or less for a maximum dimension, apparently do not show any appreciable loss; this maximum dimension, however, should be further studied as sufficient tests have not been made to give the maximum limit. Certain deep bar-wound stators, however, have shown losses up to five or six times the losses due to I^2R alone.

Deep bar secondaries show a large eddy loss at standstill, which practically disappears at slip frequency, but the reduction in eddies at slip is partially made up by an increase in reactance and, therefore, a reduction in power factor; there seems no easy way at present to determine this effect, except by an input-output test.

Core Losses

Tests were made on a machine with completely closed stator slots, having a web 0.03 in. (0.76 mm.) thick, and repeated on the same stator having a 1/16-in. (1.58 mm.) and also a ⅛-in. (3.17 mm.) opening the same rotor being used in each case, it having 1/16-in. (1.58 mm.) opening. The primary had 72 slots and the secondary 47 slots. The following are the results:

Completely closed			1/16-in. opening		1/8-in. opening	
Voltage	Watts	Amperes	Watts	Amperes	Watts	Amperes
110	52	3.62	51	3.9	54	4
220 (normal)	224	6.55	202	7.2	208	7.6
300	390	9.25	328	9.85	350	10.5

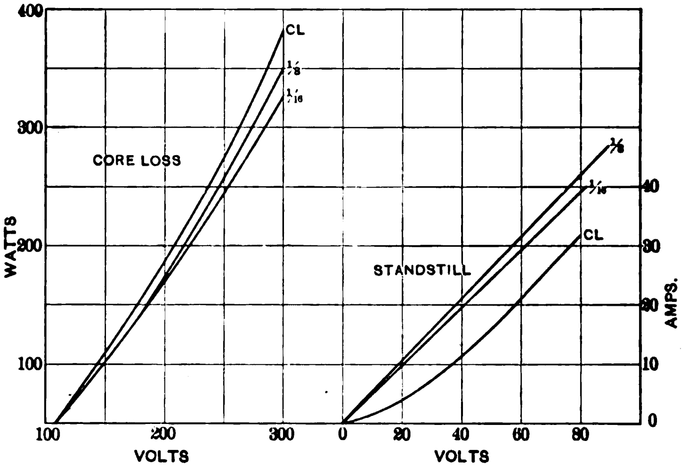
As there were eight conductors it will be noticed that the ampere conductors per slot are low.

The full load current is 25 amperes so that there will be considerable saturation and tufting of flux at load current, and, therefore, increased core loss. The following standstill voltages and currents show the effect of saturation.

Volts	Closed slots Amperes	1/16-in. opening Amperes	1/8-in. opening Amperes
20	4	9.5	10.5
30	6½	14.5	15.8
40	11.6	19.5	21.0
60	22	29.5	31.2
80	32	39	41.5

The curves herewith show more clearly the saturation effect of the completely closed slots.

A method of testing induction motors largely used in Europe measures the input by wattmeters; the core loss, friction, and primary I^2R are subtracted from the input, and is called the primary output. This is multiplied by the per cent of synchronous speed (1 per cent slip) and called the secondary output. While not strictly correct it is as close as is commercially practicable, except in cases of bar-wound stators or non-proportional impedance curves.



The losses method does not show correct results when the standstill ampere curve is bent as shown above.

Results of Tests: Load Tests

A number of tests on wire wound machines with partly open and straight slots have been made, checking efficiency and power factor by input-output method with the method of losses (A. I. E. E. method.) These cover machines from fractional to 150 h.p. From 29 tests ten showed lowest efficiency by loss method, and the remaining 19 showed lowest by brake test. The average is about three-fourths of one per cent lower by brake than by losses.

Two bar-wound stator machines showed 1.4 per cent and 3 per cent respectively, lower by load test than by losses method. Unfortunately tests were not made on the stator alone to determine eddy losses. As these were tested commercially no great accuracy should be expected, but they show a general agreement of the two methods.

The following are the results from a certain induction motor which has completely closed slots in both stator and rotor; the efficiency from method of losses was 0.881, while from an input out put test 0.774 was obtained; the power factor by losses method was 0.901, and from input output tests 0.903.

This result is rather startling, but the tests have been made carefully, and while not conclusive, show that the question of load losses on completely closed slot motors may become serious. As both stator and rotor are wire wound with small wire, and the I^2R total checks very closely with the watts at standstill, it would seem the extra losses are due to saturation of the teeth. The running light core loss is 6 per cent of the rated output.

Horse power	Rev. per min.	Efficiency by losses method	Efficiency by brake method	Difference per cent
10	1800	85.85	84.2	1.65
7½	1500	81.2	79.7	1.5
5	900	85.7	85.2	0.5
3	1200	80.4	80.5	—0.1
2	1000	80.2	79.3	0.9
1	1200	80.9	82.6	—1.5
1.5	1000	75.5	74.85	0.65
½	1200	70.1	72.2	—2.1
1	800	56.2	53.5	2.7
1/5	900	36.2	34.8	1.4
½	1200	68	70.3	—2.3
1	450	51.6	50.2	1.4
⅓	600	46.3	43.8	2.5
5	1800	85.9	84.6	1.3
7½	1800	85.5	87.4	—1.9
2	1800	82.6	84.2	—1.6
10	1800	89.8	90.3	—0.5
9	1200	84.8	86.5	—1.7
2	1800	86.6	86.3	0.3
20	1800	87.2	89.4	—2.2
1	1800	81.2	78	3.2
7½	1800	87	86.9	0.1
150	600	93.2	91.8	1.4 bar wound
36	360	88.1	85.1	3 " "
50	600	89.4	89	0.4
20	800	88.2	88.6	0.4
30	800	90.5	91	—0.5
10	1200	87.5	86	1.5
10	1200	85.6	87	1.4

A further test has been made on a motor with partly closed primary slots and completely closed rotor slots, the thickness of the web being one mm.: the core loss running light was 2.3 per cent (approximately ½ of what would be obtained if one member were of the usual straight slot construction).

At one-half load the difference in efficiency between the loss method and input output was 1.7 per cent, at three-quarter load 2.2 per cent, at full load 2.8 per cent, at one-half load 3.4 per cent. The corresponding difference in power factor was 1 per cent, ½ per cent, 0.2 per cent, and 0.2 per cent.

The load test was taken by a friction brake and is the average of a number of readings, it being necessary to take a number on account of scattering points.

The motor was designed to have a large core loss and small copper loss, therefore, the load losses, due to saturation of the thin overhang, are not as large as would be the case in a motor of more ampere turns per slot, such as a standard type.

The results, however, show a decided load loss increasing approximately proportionally to the load.

The results of these two load tests are in agreement, and seem to indicate that load losses of considerable magnitude may be expected when the iron paths are saturated, due to load current.

In connection with the above, to show the effect of tufted flux, certain tests were made on machines with and without magnetic wedges; the magnetic wedge approaches the condition of a nearly closed slot. Where the wedge was properly made and insulated the core loss was one-half to one-third of the corresponding straight slot; with a poorly insulated wedge, however, the losses increased from two to three times, showing that magnetic wedges require very careful design and handling. Due to the structure of the wedges more or less of an air path was included by the wedges and the short circuited current was directly proportional to the voltage.

The effect of filing and turning on the cores is shown as an excess core loss during the excitation or running light test; it is constant for a given machine, but is largely the cause of the different core loss measurements on duplicate machines.

Designing engineers are aware of the above conditions and the general practice at present is to build motors with an air path somewhere in the magnetic circuit of each slot.

Present experience seems to indicate that where there is no saturation or bend in the standstill or impedance curve, there are no appreciable load losses; where wire winding is used no allowances are necessary for copper losses; where bar wound machines are used it is necessary to test the stator without the rotor to determine the stator copper losses; bar wound rotors show a greater loss and a lower inductance at standstill than when running. Half or quarter frequency tests will largely determine the eddy losses which modify secondary slip and reactance. The slip is a direct measure of the secondary loss.

LOAD LOSSES OF ALTERNATING CURRENT GENERATORS

BY

W. J. FOSTER and EDGAR KNOWLTON

Presented under the auspices of the

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LOAD LOSSES OF ALTERNATING CURRENT GENERATORS

BY W. J. FOSTER AND EDGAR KNOWLTON

ABSTRACT OF PAPER

The load losses of well designed generators are relatively small and their accurate determination is difficult.

When duplicate machines are available the circulating energy method is recommended. In this method the losses of the two machines are the quantities measured, and variations of any magnitude are readily determined.

Careful tests were made on three machines to select some method of determining load losses when but one machine was available. The indications were that the load losses were approximately the same as the short circuit core loss. The few machines tested and the small load losses of these do not warrant a recommendation that the load losses be considered as equal to the short circuit core loss. It is hoped that additional data will be brought forth to establish a rule to cover this case.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26–28, 1913.

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(*Subject to final revision for the Transactions.*)

LOAD LOSSES OF ALTERNATING CURRENT GENERATORS

BY W. J. FOSTER AND EDGAR KNOWLTON

About twenty years ago it began to be recognized by designers of alternators that certain losses existed under load that were not included among the " segregated losses " taken into consideration in determining the efficiency. It was natural to give to these losses the name " load losses," since they are due to reactions set up by the current in the armature under the conditions of load, and cannot be reproduced on open circuit or calculated directly from measured current and resistance, as can the $I^2 R$ of armature and field. The current in the armature corresponding to that of any load could be easily established by simply short circuiting the armature terminals and introducing the proper exciting current into the field winding. Hence, for the lack of something more accurate, it became customary to measure the losses on short circuit in the same manner as core losses were determined, and take these as indicative of the losses that would exist under actual load. Obviously, the reactions on short circuit are exaggerated, hence, it has been considered fair to take a fraction of the short circuit losses as the load losses. The present A. I. E. E. rule, Section 117, specifies one-third as the proper amount.

The method of determining the efficiency by the " segregated losses" method is undoubtedly deficient in at least two particulars.

1. The determination of core losses at the normal potential (corrected though it may be for internal resistance and reactance) can be considered as only an approximation of that existing under the influence of armature reaction when the flux is distorted and of varying density across the magnetic circuit.

2. No satisfactory method has yet been evolved of measuring the eddy currents that may be produced directly by the current in the armature under the load conditions.

However, it may be said that any alternator that has high load losses under normal load conditions, will have high losses under short circuit. Another good criterion of the design in the matter of load losses is the static impedance test with field removed, using wattmeters to measure the energy input.

That load conditions affect the hysteresis losses, becomes very apparent when we consider the case of an unbalanced condition of load between the phases or the exaggerated condition of single-phase load, where the pulsating m.m.f. produces a flux of double frequency thereby introducing losses in parts of the magnetic circuit which are free from losses in the open circuit condition of uniform flux. That load conditions have a tendency to increase eddy current losses has been shown by the high temperatures of many alternators in actual service where the temperature increments are greater than they should be if only what may be called legitimate losses existed. In some cases temperatures have produced charring of insulation and rapid deterioration where the heating, due to the I^2r alone, should be conservative, and where the determination of segregated losses, and possibly heat runs on open circuit under what was taken to be equivalent heating, gave no indication of trouble from excessive temperatures.

Load losses may be defined as all losses due to the presence of current in the armature windings in excess of the following:

Open circuit core loss at rated $+Ir$ potential.

I^2r of armature and field due to the actual resistance of the circuits.

The load losses may be regarded as made up of two components; the necessary or legitimate, and the illegitimate. The first of these is small and hardly worth considering in its effect on the efficiency. The second may be so large as to materially lower the efficiency and seriously impair the life of the machine. On the other hand, the second component may be appreciable, and one to be reckoned with in determining the efficiency, and yet be desirable to introduce into the design. For instance, a solid is often preferable to a sectionalized conductor since the additional eddy current loss may be compensated for by greater net cross-section. Even though this compensation be partial, no greater heating may result, due to the better transfer of heat to the surface, and the use of the solid conductor is justified by the cheaper construction, greater mechanical strength and ease of repairs.

DETERMINATION OF LOAD LOSSES

In a well designed machine the magnitude of the load losses is so small compared with the capacity that it is impracticable to determine it by direct measurement of input. This has been shown by numerous trials.

A method has been proposed for machines of the enclosed type where the greater part of the losses are removed by the air passing through the machine. This consists in measuring the volume and temperature rise of the air and estimating the losses from the specific heat of the air. In this method there are the following sources of error. The percentages of error given apply to the ordinary commercial test:

Transfer of heat to the room through the frame (amount unknown).

Difference in the specific heat of air due to the presence of moisture (inappreciable).

Measurement of the volume of air (at least 5 per cent. error).

Determining the average temperature of the ingoing and outgoing air (at least 5 per cent. error).

With these errors it is evident that load losses of considerable magnitude would remain undiscovered.

A modification which eliminates most of the errors is to run the machine at some no-load condition in which the losses can be easily determined; also run the machine under load. The difference in the temperature rises of the air under the two conditions represents a certain loss which can be calculated from the no-load results. The load losses may then easily be estimated. By making such a test carefully any abnormal load losses should be detected. The authors, however, have had no opportunity to make a trial of this method.

To obtain more satisfactory results there has been devised a number of other methods based on the following plan:

The alternator is run in such a manner that all magnetic and current densities and all reactions shall be the same as under load and the energy measured be only that due to the losses. The excess of the losses thus determined over that obtained by the usual segregated loss method will represent the true load losses. Several tests of this nature have been made with more than usual care for the purposes of this paper. A general description of the tests follows and a comparison of the results is given in Table III.

Segregated Loss Method

The A. I. E. E. method of determining the total losses consists in obtaining the various losses under partial load conditions and taking their sum as the total loss making certain allowances for the load losses. The following A. I. E. E. rules relate to the losses.

102 Bearing Friction and Windage. The magnitude of bearing friction and windage (which may be considered as independent of the load) is conveniently measured by driving the machine from an independent motor, the output of which may be suitably determined.

106 Core Losses. In machines these losses should be determined on open circuit and at a voltage equal to the rated voltage $+ Ir$ in a generator, and $-Ir$ in a motor, where I denotes the current strength and r denotes the internal resistance of the machine. They should be measured at the correct speed and voltage, since they do not usually vary in any definite proportion to the speed or to the voltage.

107 Note. The total losses in bearing friction and windage, brush friction, magnetic friction and eddy currents can, in general, be determined by a single measurement by driving the machine with the field excited, either as a motor, or by means of an independent motor.

108 Retardation Method. The no-load iron, friction, and windage losses may be segregated by the Retardation Method, in which the generator should be brought up to full speed (or, if possible, to about 10 per cent. above full speed) as a motor, and, after cutting off the driving power and excitation, frequent readings should be taken of speed and time, as the machine slows down, from which a speed-time curve can be plotted. A second curve should be taken in the same manner, but with full field excitation; from the second curve the iron losses may be found by subtracting the losses found in the first curve.

109 The speed-time curves can be plotted automatically by belting a small separately excited generator (say 1/10 kw.) to the generator shaft and connecting it to a recording voltmeter. When the retardation method is not feasible, the fractional losses in bearings and in windage, which ought, by definition, to be included in determining the efficiency may be excluded; but this should be expressly stated.

110 Armature-Resistance Loss. This loss may be expressed by $p\ I^2r$: where r resistance of one armature circuit or branch, I = the current in each armature circuit or branch, and p = the number of armature circuits or branches.

114 Load Losses. The load losses may be considered as the difference between the total losses under load and the sum of the losses above specified.

116 Estimation of Load Losses. While the load losses cannot well be determined individually, they may be considerable and, therefore, their joint influence should be determined by observation. This can be done by operating the machine on short circuit and at full load current, that is, by determining what may be called the "short circuit core loss." With the low field intensity and great lag of current existing in this case, the load losses are usually greatly exaggerated.

117 One-third of the short circuit core loss may, as an approximation, and in the absence of more accurate information, be assumed as the load loss.

In order to have a comparison of the value of the short-circuit core loss and the other armature losses, there have been prepared Tables I and II on 25- and 60-cycle generators, respectively. The accuracy of the individual determination may be questioned, but they are given, as it is probable that the average of all the values is approximately correct. The data on horizontal lines 3, 4, 5, 6, 8, 9, 10, and 11 in Table I, and 2, 3, 4, 5, 6, 7, 8, 9, 11, 14, 15, 16, 19, 20, 29, 33, 36, 39, 40, 42 and 43 in Table II, are on steam turbo-generators and the core losses were taken by the retardation method with turbine wheels assembled; consequently the results are not especially accurate. The core losses on the other machines were taken by driving with a direct-current motor and are more reliable.

TABLE I.

OPEN CIRCUIT, SHORT CIRCUIT, AND Ir LOSSES OF 25 CYCLE ALTERNATING CURRENT TWO AND THREE PHASE GENERATORS.

	1	2	3	4	5	6	7
			Losses in per cent of kv-a.				
	Kv-a.	Volts	Core loss			I^2r arm.	Total 3 +5 + 6
			Open cir.	Short cir.	⅓ of s.c.		
1	270	2300	1.74	0.00	0.00	2.08	3.82
2	360	2300	3.17	0.29	0.1	0.90	4.17
3	937	2300	0.95	0.24	0.08	0.95	1.98
4	937	3300	1.47	0.71	0.24	1.04	2.75
5	937	6600	1.05	0.60	0.20	0.94	2.19
6	1111	220	2.07	1.46	0.49	0.68	3.22
7	360	13200	2.39	0.88	0.29	1.16	3.84
8	1667	2300	1.88	0.80	0.27	0.70	2.85
9	1667	6600	1.07	0.49	0.16	0.50	1.73
10	2222	2300	1.21	0.79	0.26	0.83	2.30
11	2342	480	1.40	1.00	0.33	0.80	2.53
12	430	480	1.56	0.71	0.24	1.67	3.50
13	420	240	2.05	1.01	0.34	3.08	5.47
14	1270	9000	1.33	0.54	0.18	0.82	2.33
15	840	480	1.58	0.59	0.20	1.70	3.48
16	720	480	1.64	0.81	0.27	2.09	4.00
17	1800	2300	2.11	0.29	0.1	1.24	3.45
18	9000	6600	1.00	0.28	0.09	0.44	1.53
Average	1516	3416	1.65	0.64	0.21	1.2	3.06

No. of machines above the average short-circuit core loss, 9.
No. of machines below the average short-circuit core loss, 9.

TABLE II. OPEN CIRCUIT, SHORT CIRCUIT, AND $I r$ LOSSES OF 60-CYCLE ALTERNATING-CURRENT TWO- AND THREE-PHASE GENERATORS.

	1	2	3	4	5	6	7
			Losses in per cent of kv-a.				
	Kv-a	Volts	Core losses			I^2R arm.	Total 3 + 5 + 6
			Open cir.	Short cir.	⅓ of s.c.		
1	318	2300	1.41	0.52	0.17	1.18	2.76
2	625	2300	1.59	0.71	0.24	1.10	2.93
3	1875	2300	1.38	1.68	0.56	0.38	2.22
4	937	600	1.60	0.96	0.32	0.66	2.58
5	937	2300	1.45	1.18	0.06	0.44	2.28
6	420	2300	1.37	0.18	0.06	1.10	2.56
7	1250	2300	1.55	0.90	0.30	0.92	2.77
8	1563	480	1.31	0.83	0.28	0.69	2.28
9	1563	2300	1.31	0.83	0.28	0.51	2.10
10	480	600	1.63	1.06	0.35	1.19	3.17
11	2000	2300	1.04	0.29	0.10	0.62	1.76
12	635	2300	1.48	0.43	0.14	1.06	2.68
13	793	2300	1.51	0.72	0.24	0.55	2.33
14	2500	480	1.30	0.25	0.08	0.40	1.78
15	2500	2300	1.82	0.43	0.14	0.41	2.37
16	2500	6600	1.85	0.09	0.03	0.33	2.21
17	600	600	1.98	0.50	0.17	1.18	3.33
18	600	480	2.63	1.32	0.44	1.34	4.41
19	3125	2300	1.63	0.99	0.33	0.40	2.36
20	3125	2300	1.66	0.34	0.11	0.35	2.12
21	635	4150	1.99	0.64	0.21	1.18	3.38
22	480	11000	2.53	0.26	0.09	1.65	4.27
23	370	600	1.49	0.22	0.07	1.52	3.08
24	720	600	2.87	1.15	0.38	0.94	4.19
25	600	11000	2.53	0.25	0.08	1.47	4.08
26	540	220	2.28	0.95	0.32	1.27	3.87
27	1920	2300	1.61	1.32	0.44	0.54	2.59
28	720	600	1.54	0.25	0.08	1.15	2.77
29	6250	4000	0.96	0.43	0.14	0.31	1.41
30	1275	11000	1.51	0.74	0.25	1.00	2.75
31	1200	10000	2.73	0.38	0.13	0.98	3.84
32	1440	2300	1.83	1.25	0.42	0.73	2.98
33	8333	2200	1.05	0.53	0.18	0.31	1.54
34	1200	2300	1.50	0.49	0.16	1.34	3.02
35	6000	2300	0.91	0.51	0.17	0.53	1.61
36	9000	4600	1.00	0.13	0.04	0.30	1.34
37	3000	2300	1.33	0.47	0.16	0.75	2.26
38	12000	6600	1.18	0.24	0.08	0.32	1.58
39	14000	4600	0.87	0.05	0.02	0.31	1.20
40	14000	6000	1.45	0.09	0.03	0.24	1.72
41	15000	4150	0.70	0.48	0.16	0.36	1.22
42	15000	7000	0.91	0.15	0.05	0.25	1.21
43	15000	11431	1.45	0.34	0.11	0.20	1.76
44	7800	4000	1.28	0.55	0.18	0.50	1.96
45	9800	6900	1.58	0.72	0.24	0.40	2.22
46	12000	6600	1.72	0.20	0.07	0.32	2.11
47	6600	4000	1.89	0.43	0.14	0.53	2.56
Average	4111	3670	1.58	0.58	0.19	0.72	2.49

Number of machines above the average short circuit core loss, 18.
Number of machines below the average short circuit core loss, 29.

A description of Tables I and II follows:

Column 1. Kv-a. rating. This is on the "continuous" or "single rating" basis, which is being considered in the present revision of rules.
" 2. Potential.
" 3. Open circuit core loss at rated + Ir volts (in per cent of kv-a. rating).
" 4. Short circuit core loss at rated current (in per cent of kv-a. rating.
" 5. One-third of the values in column 4.
" 6. Calculated I^2r loss of armature at rated current in per cent of the kv-a. rating.
" 7. Total of columns 3, 5, and 6.

In addition to the data given in Tables I and II there were a few accurate tests made, the results of which are included in Table III.

MODIFIED SEGREGATED LOSS METHOD

This method differs from the segregated loss method in that the reactive drop of the armature current is taken into account. The core loss is taken at a voltage corresponding to rated volts plus IR drop plus IX drop. The IX drop is determined as follows:

Let A = Ampere turns field to pass full load current through the armature when it is short circuited.
R = ampere turns of armature reaction.
ϕ = angle of lag between volts and current.
X = IX drop which is the volts from the no-load saturation curve corresponding to $A-R$.
V = rated volts.
V_m = volts at which the core loss is taken.

$$V_m = \sqrt{V^2 + X^2 + 2\,VX \sin\phi}$$

See Table III for results of tests.

PHASE CHARACTERISTIC METHOD

This method of testing consists in running an alternating current generator as a synchronous motor without mechanical load at rated voltage and current. The energy input is taken for the above conditions of voltage and current with field under- and over-excited. From the average of these two quantities there is subtracted the I^2r of the armature winding and the energy input at unity power factor and rated voltage.

See Table III for results of tests.

CIRCULATING ENERGY METHOD

This tests consists in coupling two alternators mechanically and electrically, and belting a direct-current motor to the combination to supply the losses. The angle of the two rotors is shifted by means of slots in the coupling so that rated current will flow with rated volts at unity power factor.

The losses of the two machines are determined by the input from the driving motor.

See Table III for the results of tests.

TABLE III.
RESULTS OF CAREFUL TESTS BY SEVERAL DIFFERENT METHODS OF DETERMINING LOAD LOSSES. 60 CYCLE ALTERNATORS.

	1	2	3	4	5	6	7
				Losses in per cent kv-a.			
	Phase	kv-a.	Rev. per min.	Seg.	Mod. seg.	Phase char.	Circ. energy
1	3	860	720				
2	Excess loss				0.035		
3	½ short circ. core loss			0.151	0.151		
4	Total load losses			0.151	0.186	0.302	0.49
5	1	600	720				
6	Excess loss				0.025		
7	½ short circ. core loss			1.300	1.300		
8	Total load losses			1.300	1.325		3.82
9	3	300	600				
10	Excess loss				0.063		
11	½ short circ. core loss			0.099	0.099		
12	Total load losses			0.099	0.162	0.150	0.29
13	3	110	900				
14	Excess loss				0.055		
15	½ short cir. core loss negligible						
16	Total load losses				0.055		0.359

DESCRIPTION OF TABLE III

Column 1. Number of phases.
" 2. Capacity in kv-a.
" 3. Revolutions per minute.
" 4. Losses in per cent of kv-a. by the segregated method. Note that all losses are in actual per cent. For instance the loss for line 3 in this column is 1.3 kw.
" 5. Losses by modified segregated method.
" 6. Losses by phase characteristic method.
" 7. Losses by the circulating energy method.

Line 1. Rating of the alternator.
" 2. Excess core losses. The difference between open circuit core losses at the higher potential and at the rated + *I r* potential according to modified segregated method.
" 3. One-third of short circuit core loss.
" 4. Total load losses as determined by the various methods.

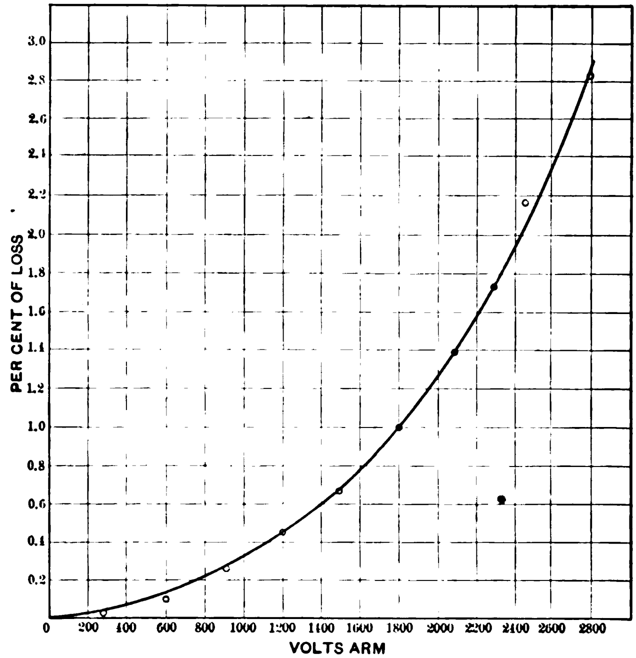

FIG. 1.—OPEN-CIRCUIT CORE LOSS.
Three-phase, 300-kv-a., 60-cycle, 2300-volt, 600-rev. per min. generator.

Lines 5 to 8 inclusive: These give the same relative data as lines 1 to 4 inclusive. The difference being that lines 1 to 4 refer to three-phase, and 5 to 8 to single-phase operations of the same generator.

Lines 9 to 12 inclusive: These give the same relative data on a 300-kv-a. alternator as lines 1 to 4 inclusive.

Lines 13 to 16 inclusive: These give the same relative data on a 110-kv-a. alternator as lines 1 to 4 inclusive.

As a matter of interest there have been included Figs. 1 to 11 inclusive, which relate to the characteristics of the machine tested.

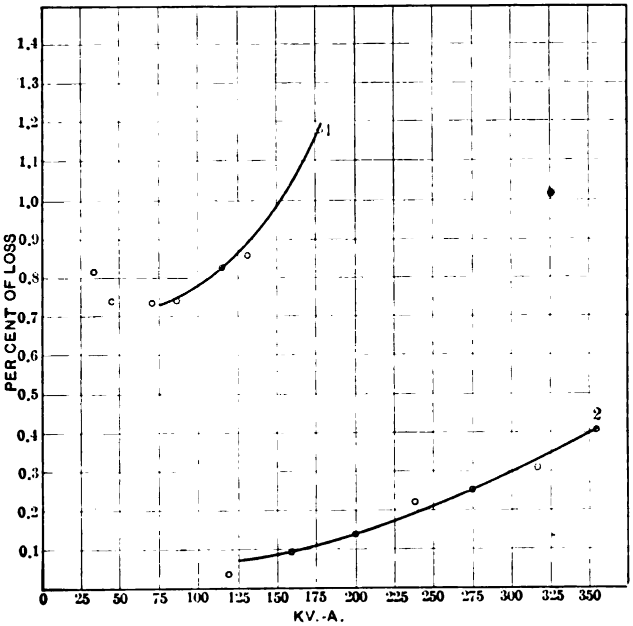

FIG. 2.—SHORT-CIRCUIT CORE LOSS.

Three-phase, 300-kv-a., single-phase, 150-kv-a., 60-cycle, 2300-volt, 600-rev. per min. generator

Curve 1—Short-circuit core loss, single phase.

Curve 2—Short-circuit core loss, three-phase.

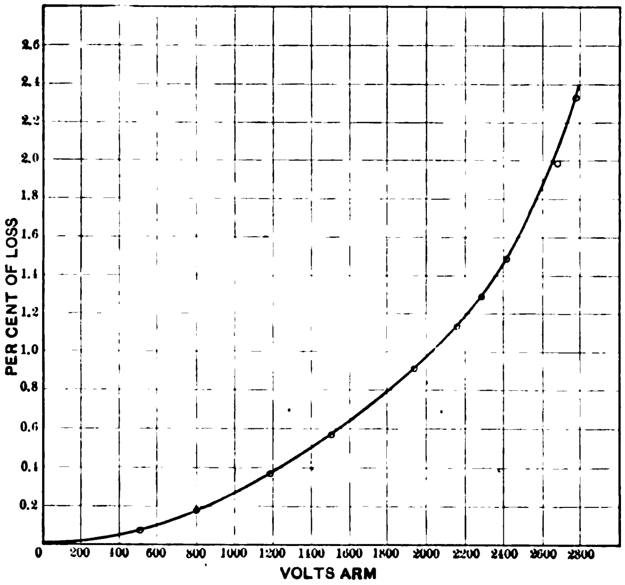

FIG. 3.—OPEN-CIRCUIT CORE LOSS.

Three-phase, 860-kv-a., 60-cycle, 2300-volt, 720-rev. per min. generator.

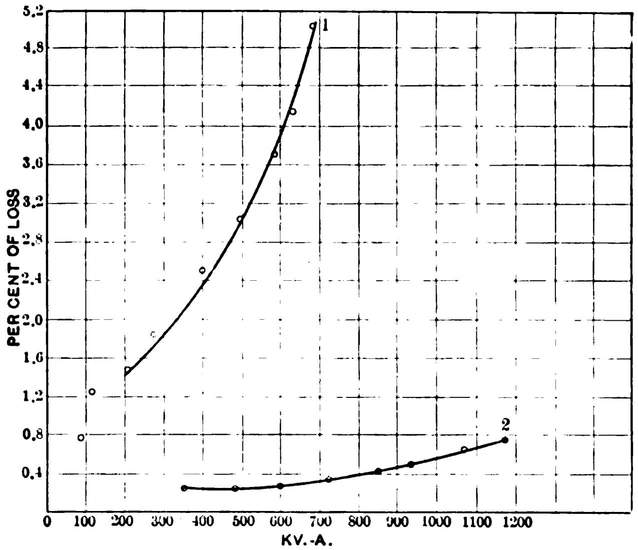

FIG. 4.—SHORT-CIRCUIT CORE LOSS.

Three-phase-860-kv-a, single-phase, 600-kv-a., 60-cycle, 2300-volt, 720-rev. per min. generator

Curve 1—Short-circuit core loss, single-phase.
Curve 2—Short-circuit core loss, three-phase.

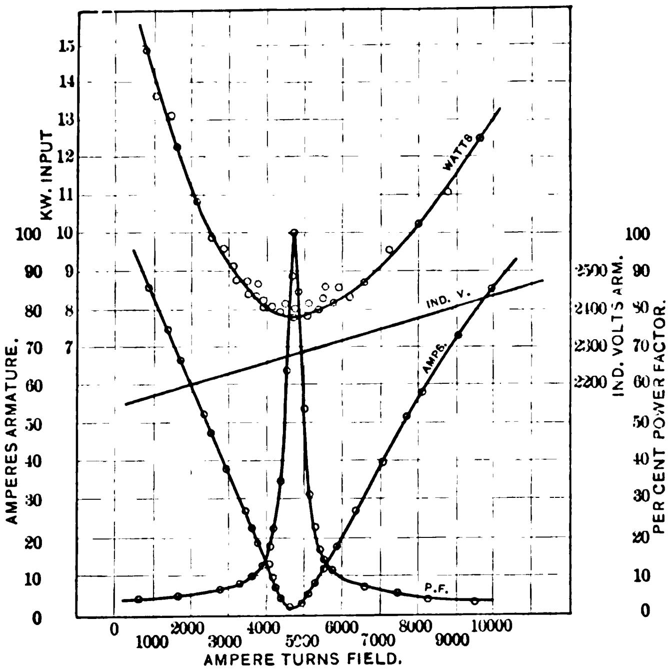

FIG. 5.—PHASE CHARACTERISTICS.

Three-phase, 300-kv-a., 60-cycle, 2300-volt, 600-rev. per min. generator.

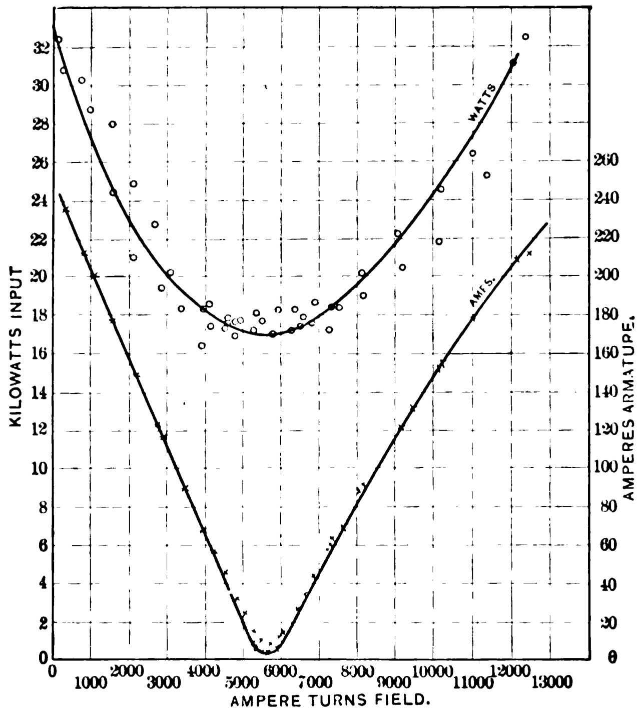

FIG. 6.—PHASE CHARACTERISTICS.
Three-phase, 860-kv-a., 60 cycle, 2300-volt, 720-rev. per min. generator.

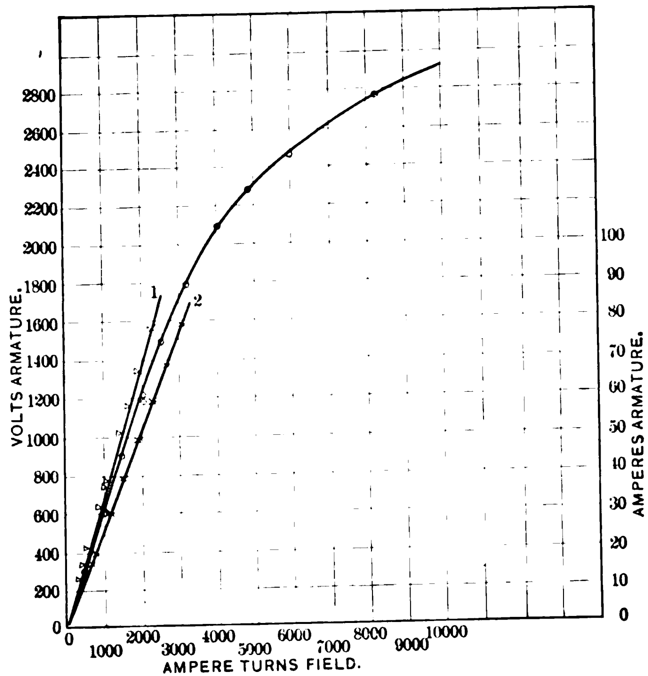

FIG. 7.—SATURATION AND SYNCHRONOUS IMPEDANCE.
Three-phase, 300-kv-a., single-phase, 150-kv-a., 60-cycle, 2300-volt, 600-rev. per min. generator
Curve 1—Single-phase synchronous impedance
Curve 2—Three-phase " "

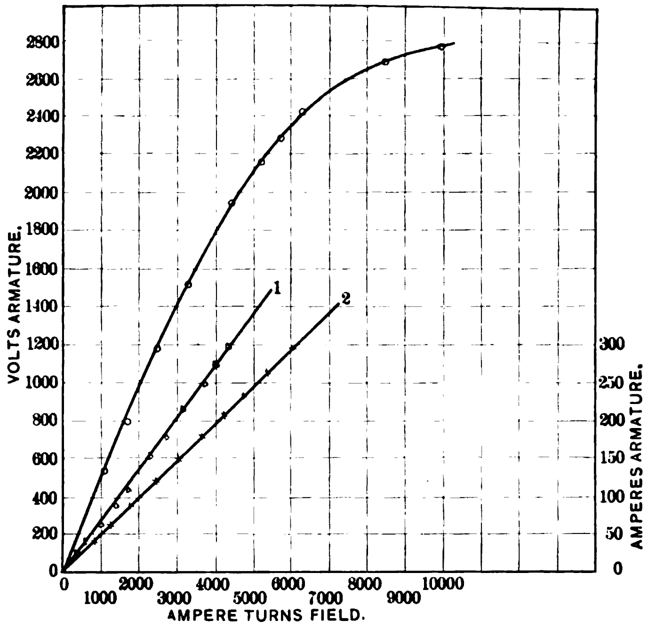

FIG. 8.—SATURATION AND SYNCHRONOUS IMPEDANCE.
Three-phase, 860-kv-a., single-phase, 600-kv-a., 60-cycle, 2300-volt, 720-rev. per min. generator
Curve 1—Single-phase synchronous impedance
Curve 2—Three-phase " "

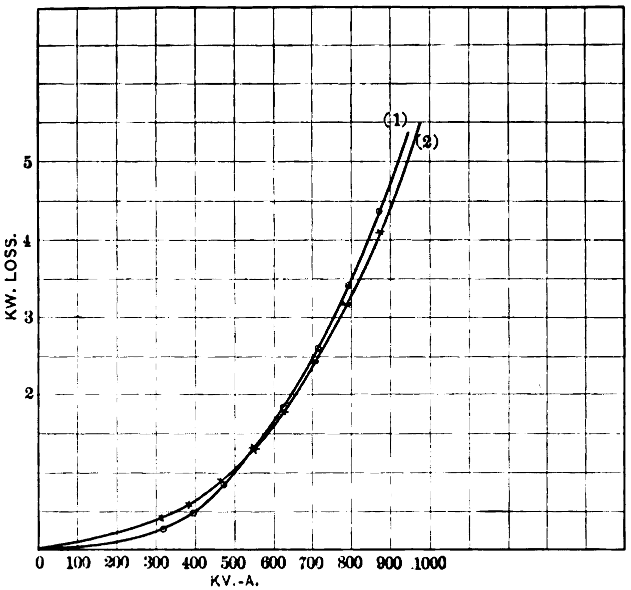

FIG. 9.—LOAD LOSSES.
Three-phase, 860-kv-a., 60-cycle, 2300-volt, 720-rev. per min. generator
Curve (1) (0)—Load loss (circulating energy method).
Curve (2) (x)—Short-circuit core loss

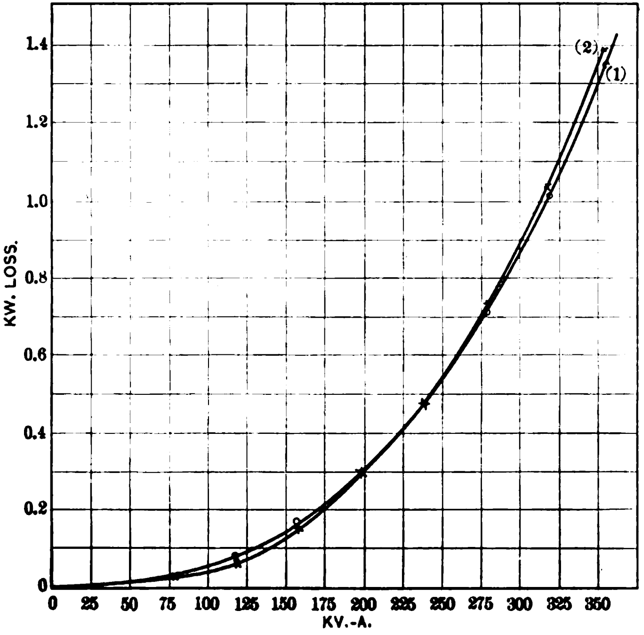

FIG. 10.—LOAD LOSSES.

Three-phase, 300-kv-a., 60-cycle, 2300-volt, 600-rev. per min. generator
Curve (1) (o)—Load loss (circulating energy method).
Curve (2) (x)—Short-circuit core loss.

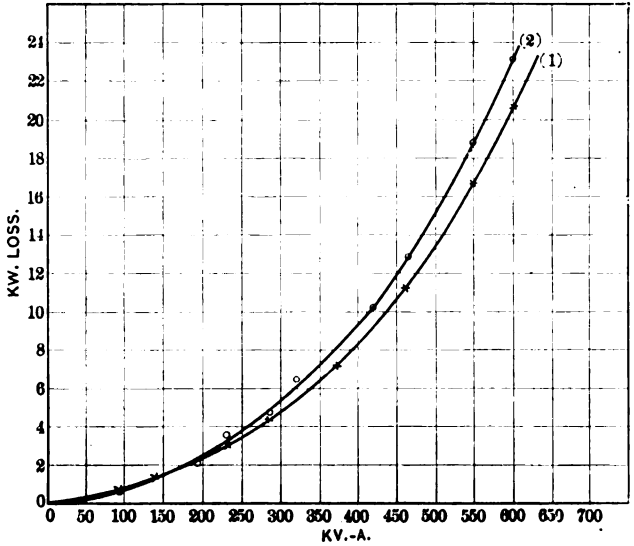

FIG. 11.—LOAD LOSSES.

Single-phase, 600-kv-a., 60-cycle, 2300-volt, 720-rev. per min. generator.
Curve (1)—Single-phase load loss (circulating energy method).
Curve (2)—Single-phase, short-circuit core loss.

SUMMARY

The circulating energy method is a form of input-output tests which eliminates the errors due to the measurement of energy equal to the capacity of the machine. When two duplicate machines are available, the authors consider it the best of the four methods.

The phase characteristic method is faulty, due to the difficulty of obtaining accurate wattmeter readings at the low power factors.

The *total* short-circuit core loss agrees closely with the load loss by the circulating energy method for the 860 kv-a. and the 300-kv-a. three phase generators. It is to be regretted that careful short-circuit core loss and circulating energy tests could not be made on several polyphase machines having a large short-circuit core loss, such as those on lines 6 and 11, Table I; and lines 3, 5, and 27, Table II. A single-phase short circuit core loss taken on the 860-kv-a. three-phase generator mentioned above showed unexpectedly high values. This led to the taking of a careful circulating energy test with a single-phase load. The close agreement of the two is shown on Fig. 11.

The small number of careful tests which it was possible to make for this paper does not warrant any recommendation for the determination of load losses when but one machine is available. Investigations should continue until a rule can be established to cover such cases.

THE HEATING OF CABLES CARRYING CURRENT

BY

SAUL DUSHMAN

Presented under the auspices of the

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THE HEATING OF CABLES CARRYING CURRENT

BY SAUL DUSHMAN

ABSTRACT OF PAPER

The current carrying capacity of an insulated cable may be calculated from data on the thermal resistivity of the insulation and of the surface. It has been shown that such data may be obtained for any type of insulation from experiments on the cable itself, by applying a well-known method for determining heat conductivities.

As a result of experiments on different types of cable insulation, the following values have been obtained for the thermal resistivities (deg. cent. per watt per inch cube).

Rubber and cotton braid cover	250
Varnished cambric and cotton braid cover	400
" " (lead covered cables)	300

For the surface resistivities, the following values were obtained (deg. cent. per watt per square inch).

Painted steel braided armor	100
Cotton covering	120
Lead, ordinary	190
" painted dull black	140

These data have been used to calculate the carrying capacities of standard rubber and varnished cambric insulated cables in air. It has been shown that the current density (i/s) and the ratio of the outside diameter (D) to the cross-section (S) are connected by an equation of the form

$$\log\left(\frac{i}{S}\right) = N\log\left(\frac{D}{S}\right) + B$$

where N is a constant for any type of insulation, and B depends upon the temperature rise.

The effect of the surface resistance on the carrying capacity has been shown to be much greater, in general, than that of the internal thermal resistance of the insulation. The magnitude of the surface losses is thus of great importance in determining the current carrying capacities of cables.

Approximate equations have been worked out for calculating the rates of heating and cooling of insulated cables and the application has been indicated to determining the carrying capacities under intermittent use.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26-28, 1913.

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(*Subject to final revision for the Transactions.*)

THE HEATING OF CABLES CARRYING CURRENT

BY SAUL DUSHMAN

The problem of determining the current carrying capacity of a cable or wire for a given rise of temperature has been the subject of a number of investigations since the appearance of the classical paper by Professor Forbes in 1884. That, however, the last word has not been said on this subject is evidenced by the fact that during 1910 and 1911 an elaborate investigation was carried out at the National Physical Laboratory, England, at the request of the Wiring Rules Committee of the Institution of Electrical Engineers.[1]

While the present investigation was undertaken mainly with the object of obtaining data for calculating the carrying capacity of a special type of cable, it has been thought that a description of the methods used as well as the publication of some of the results obtained might be of interest in connection with the general subject of heat losses.

I. Description of Method

The carrying capacities of insulated cables may be determined either directly or indirectly. In the former case the actual rise in temperature is determined for a given current either by noting the increase in resistance of the conductor (*e.g.*, Melsom and Booth,) or by means of thermo-couples placed in thermal contact with the conductor itself. By carrying out tests with a number of different sizes under varying conditions of temperature rise, an empirical relation is obtained from which the carrying capacity may be calculated for any given rise in temperature.

---

[1] S. W. Melsom and H. C. Booth, The Heating of Cables with Current. *Journ.* Inst. Electrical Engineers (Eng.) 47, 711-751 (1911). A fairly complete list of references to previous investigations will be found at the end of their paper.

In the indirect method the carrying capacity is calculated from the thermal resistivity of the insulation and the emissivity of the surface. The method has the obvious advantages of requiring a far smaller number of experimental data and of being much more generally applicable, especially in those cases where the design of fresh cable insulations is involved.

TABLE I

NOMENCLATURE

d = Diameter in inches of conductor.
D_1 = Diameter over first layer of insulation.
D_n = “ “ nth “ “ “
S = Cross-section of conductor, in square inches.
$= \nu \times \delta^2 \times \pi/4$ for stranded conductors.
ν = Number of wires in stranding.
δ = Diameter of individual wire in inches.
π = 3.1416
T = Maximum rise in temperature in deg. cent.
Θ = Temperature rise (variable).
x = Distance from heated end, in inches.
R = Electrical resistance per 1 inch of conductor, at 25 deg. cent.

$$= \frac{0.691 \times 10^{-6} \times 1.02}{S} \text{ for stranded conductors.}$$

$$= \frac{0.691 \times 10^{-6}}{S} \text{ for solid conductors;}$$

R_T = Electrical resistance per 1 inch at $T + 20$.

$$= \left(\frac{258 + T}{263}\right) R$$

K_1 = Thermal resistivity (*in deg. cent. per watt per inch cube*) of material of first layer.
H = Surface resistivity (in deg. cent. per watt per square inch).
K_n = Thermal restivity of material of nth layer.
r_n = Thermal resistance of nth layer of insulation per 1 inch length of cable.

$$= 0.365\, K_n \log \frac{D_n}{D_{n-1}}$$

Σr = Total internal thermal resistance of insulation per 1 inch length.

r_e = external resistance per 1 inch length.

$= \frac{H}{\pi D_n}$

W = Permissible watts per one inch length for rise of 1 deg. cent.

$= \frac{1}{\Sigma r + r_e}$

i = Current in amperes.

C = Heat capacity of cable per 1 inch length, in *watt seconds.*

b = " Constant " in equation for rate of heating.

$= \frac{60\, W}{C}$

It is evident that after current has been passing through the conductor for a certain interval of time, a stationary state is attained at which the heat generated per unit length of cable is completely conducted through the insulation and dissipated at the surface. Under these conditions,

$$i^2 R_T = \frac{T}{\frac{2.3}{2\pi}\left[K_1 \log \frac{D_1}{d} + K_2 \log \frac{D_2}{D_1} + \ldots\right] + \frac{H}{\pi D_n}} \tag{1}$$

The nomenclature used in this and the following equations is that given in Table I.

Equation (1) may be written in the more convenient form:

$$i^2 R_T = \frac{T}{\Sigma r + r_e} \tag{2}$$

Data on the heat resistivity of electrical insulations have been published by H. D. Symons,[2] Professor Porter[3] C. P. Randolph[4] and A. Winkelmann[6].

Regarding H, it is known that for a " perfect " radiator the value may be as low as 100 (expressed in degrees centigrade per watt per square inch) while for imperfect radiators it becomes as high as 200.

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[2] *Journ.* Inst. Electrical Engineers (Eng.) read Nov. 29, 1911.

[3] *Phil. Mag.* 20, 511 (1910).

[4] *Trans.* Am. Electrochem. Soc. 21, 545 (1912)

[6] Handbuch der Physik, III. 504, (1906).

The great difficulty in applying equation (1) consists in determining what value of H should be used, since, it varies so greatly with the nature of the surface. Furthermore the data obtained for K on the insulation itself by the usual methods for determining heat conductivity may be altogether different from the value for the insulation on the cable, owing to conditions of manufacture.

In view of these considerations a method was adopted for determining the terms Σr and r_e [equation (2)] separately on the cable itself. Knowing the values of d and D for the cable it is then possible to calculate Σr and r_e for all other sizes.

This method, originally used by Despretz, is described in standard works on heat[7]. If we heat one end of a piece of cable which is so long that the other end always remains at room temperature, the relation existing at the stationary state between the rise in temperature, Θ, and the distance, x, from the heated end, will be given by the differential equation

$$\frac{d^2\,\theta}{d\,x^2} = \mu^2\,\theta^p \tag{3}$$

where

$$\mu^2 = \frac{K'}{S\,(\Sigma\,r + r_e)} \tag{4}$$

K^1 = Thermal resistivity of materials of conductor.
S = Cross-section of conductor.
p = A constant.

For temperatures below 100 deg. cent., p is practically equal to 1; and the solution of (3) therefore assumes the familiar form[8]

$$\log_e \theta = -\,\mu\,x + \log_e \theta_1 \tag{5}$$

where θ_1 denotes the temperature rise at $x = 0$.

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[7] Preston, Theory of Heat, pp. 631-636 A. Winkelman, Handbuch der Physik, III. Wäime, p. 451 (1906)

[8] For values of p only slightly greater than 1, it can readily be shown that the solution of (3) may be written in the form

$$\log_e \theta \left\{ 1 - \frac{p-1}{4}\log_e \theta \right\} = -\,\frac{\mu}{\sqrt{\dfrac{p+1}{2}}}\,x + \log_e \theta_1 \left\{ 1 - \frac{p-1}{4}\log_e \theta_1 \right\} \tag{5a}$$

By placing thermo-couples in small holes drilled through the insulation at different points, it is therefore possible to determine μ and by noting the temperature on a couple in contact with the covering of the insulation it is further possible to determine the ratio Σr to r_e. The method thus gives, in one experiment, data from which both the thermal resistivity (K) of the particular insulation as actually put on the cable, and the surface resistivity (H) may be determined.

II. EXPERIMENTAL

Lengths of about five feet of each of the cables described below were used in the experiments. A few inches at one end were bared and the conductor surrounded by a heating coil. The heated end was packed in some good heat insulating material contained in a wooden box, so that no heat would penetrate the cable insulation except through the conductor. Holes were drilled through the insulation into the copper at distances of three or five inches apart, a small mercury globule dropped into the bottom of each hole, and calibrated thermo-couples (No. 10 B. & S. calorite-advance) placed in the holes

Description of Cables Tested. (For meaning of symbols consult Table I.)

Cable A.	500,000 cir. mils. $\nu = 61$ $\delta = 0.0906$, $d = 0.8154$. *Rubber insulation*, $D_1 = 1.003$; cotton braiding impregnated with asphaltum, $D_2 = 1.12$. $S = 0.393$ $R = 1.793 \times 10^{-6}$
Cable B.	0000 solid conductor, $d = 0.46$. *Varnished cambric insulation*, $D_1 = 0.616$; asbestos and cotton braiding, $D_2 = 1.06$. $S = 0.166$ $R = 4.16 \times 10^{-6}$
Cable B-1.	Same as *B*; cotton and asbestos covering removed.
Cable C.	250,000 cir. mils. $\nu = 37$, $\delta = 0.0823$, $d = 0.5754$ *Varnished cambric insulation*, $D_1 = 0.952$; lead covering, $D_2 = 1.14$. $S = 0.196$ $R = 3.582 \times 10^{-6}$
Cable C-1.	Same as C. Lead painted dull black.
Cable D.	*Three-conductor cable*, each conductor 250,000 cir. mils. *Varnished cambric insulation* on each conductor, $D_1 = 0.70$. Jute and compound between conductors and outside layer of varnished cambric, diameter over three conductors, 1.640. *Varnished cambric insulation*, $D_1 = 1.765$; lead covering, $D_2 = 1.984$.

Cable D-1. Same as *D*. Lead painted dull black.

Cable E. 250,000 cir. mils, $d = 0.5754$ rubber insulation, $D_1 = 0.825$; lead casing, $D_2 = 0.935$; tape treated with rubber compound, $D_3 = 1.007$; braided with galvanized steel wire and thoroughly painted $D_4 = 1.07$.

$S = 0.196$ $R = 3.582 \times 10^{-6}$

The thermo-couples used gave an electromotive force of about 0.04 millivolts per deg. cent. Under the actual experimental conditions a rise of temperature of 1 deg. cent. produced a deflection of 6.4 millimeters on the scale, at one meter. Denoting the deflection by α, it is evident from the proportionality between θ and α in the range of temperatures used (20-60 deg. cent.) that in equation (**5**) we could substitute α for θ.

TABLE II.

EXPERIMENTS ON CABLES C AND C-1

Deflection at $x =$

No. of Expt.	2	5	8	11	14	17	20	23	μ
1	438	338	257	203	156	120	91	68	0.0860
	(438)	338	261	202	156	121	93	72	(Calculated)
2	427	320	240	180	138	103	76	55	0.0947
	(427)	320	240	180	135	101	76	57	(Calculated)
3	411	307	225	169	130	96	71	51	0.0958
	(411)	307	230	173	130	97	72	55	(Calculated)
4	420	313	231	174	132	97	71	50	0.0971
	(420)	315	236	177	133	99	74	56	(Calculated)

While theoretically it is only necessary to obtain values of θ for two different values of x in order to calculate μ, readings were usually taken at five or more different points along the cable. The values of log α were then plotted as ordinates with corresponding values of x as abscissas. From the straight line drawn through all the points (or so to take in as many points as possible) an average value of μ was then determined.

To check the results, the average value of μ from all the experiments on any one cable was then used to recalculate the deflections on the galvanometer scale corresponding to the different points.

The temperature at the surface was very easily determined in case of lead-covered cables by drilling holes into the lead and securing an intimate contact between the lead and the couple by means of a mercury globule. In the case of cotton-covered cables, the couple was cemented to the surface by means of Canada balsam and a narrow band of tape.

As an illustration of the results obtained the Table II gives the observations in four experiments with cables C and C-1. In the last three of these the lead-covering was painted dull black.

In experiment 1, the deflections were recalculated from $\mu = 0.086$, in the other experiments the average value from the three experiments was used to recalculate the deflections. When it is considered that a deflection of 6.4 corresponded to a difference of 1 deg. cent., the agreement must be considered quite satisfactory.

TABLE III.

									Calculated	
Cable	μ	$\Sigma r + r_e$	W	$r_e W$	Σr	r_e	H	K	Σr	r_e
A	0.0765	47	0.0213	0.74	12.2	34.8	122	242	12.6	34.1
B	0.085	90	0.0111	0.40	54	36	120	410	—	—
B-1	0.095	72	0.0139	0.79	15.1	56.9	110	330	18	62
				0.69	22.3	49.9	97	480		
C	0.086	74	0.0135	0.69	23	51	183	290	24	53
C-1	0.096	59.5	0.0168	0.61	23.2	36.3	130	290	24	39
				0.62	22.6	36.9	132	283		
D	0.0652	43	0.0233	0.71	12.4	30.6	191	288	12.9	31
D-1	0.74	33.4	0.0300	0.69	10.3	23.1	144	240	12.9	23
				0.65	11.3	22.1	138	261	12.9	22
E	0.110	45.5	0.022	0.59	18	27.5	91	260	18	32

By means of equation (**4**) values of $(\Sigma r + r_e)$ were calculated from the values of μ. In accordance with the most recent data on the thermal conductivity of copper[9] I have used the value $K' = 0.108$.

In Table III are tabulated the values of μ, $\Sigma r + r_e$; W; r_e. W; r_e and Σr. The value of

$$r_e W = \frac{r_e}{\Sigma r + r_e}$$

was obtained from the temperature readings on the couples inside and outside the layer of insulation. From r_e and D_n, the value of H was determined as indicated in equations (**1**) and (**2**). From $\Sigma\, r$ the average value of K for the different materials composing the insulation was determined in the same manner.

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[9] Jaeger and Disselhorst, Wiss. Abh. d. Phys. Techn. Reichsanstalt, 3, 269 (1900).

Assuming K for treated tape to be about 270 (Symons) and that the resistivity of the cotton braiding and rubber are approximately equal, we can deduce from the above experiments the following values of K for different materials:

Rubber	250
Varnished cambric (lead-covered cables)	300
" " (cotton " "	400

In view of the influence of slight errors in the experimental observations on the values of K, only round numbers have been given.

The difference in the thermal resistivities of the lead covered and cotton-covered varnished cambric insulations, is no doubt due to the presence of air spaces between the insulation and covering in the latter case.

For the surface resistivity H, the numbers deduced from the above experiments are as follows:

H for different surfaces

Painted steel braided armor	100
Cotton covering	120
Lead, ordinary smooth	190
" painted dull black	140

In the last two columns of Table III are given the values of $\Sigma\, r$ and r_e calculated by means of these data.

The most striking feature about these results is the effect of painting the lead on its surface resistivity. The fact that $\Sigma\, r$ remains constant while r_e alone varies as a result of painting the surface is very strikingly brought out by the results recorded in Table III. (Compare C and C-1; D and D-1). That consequently, the current carrying capacity of the cables is thereby increased is also seen from the carrying capacities given in Table IV as calculated by means of equation (**2**).

Table IV shows that by painting the single conductor lead cable, the carrying capacity for $T = 60$ deg. cent, is increased about 11.4 per cent., while in the case of the three-conductor cable the increase is 13.5 per cent. While this is quite in accord with what is known about the laws of surface losses, it is interesting to note that by ***painting the lead-covered cable the carrying capacity can be increased as much as* 12 *per cent.***

Note on the Calculation of K for Varnished Cambric Insulation from Σr for Three-Conductor Cable. In comparing the values obtained for Σr in the case of cables C and D and of C-1 and D-1 it was found that the results could be calculated fairly well by assuming that the only effective thermal resistance in the case of three conductor cables is the sum of the resistance of insulation on one of the conductors together with that of the covering, to which must of course be added the surface resistance.

Thus in the case of Cable D (or D-1),

$$\Sigma r = 300\left(0.365\log\frac{0.70}{0.5754} + .365\log\frac{1.765}{1.640}\right)$$
$$= 12.9.$$

instead of 10.3 to 12.4 as obtained experimentally.

TABLE IV.

		i for T =				
Cable	*W*	60	40	30	20	10
A	0.0213			571	475	342
B	0.0111	365	307	270		
C	0.0135	433	365	321		
C-1	0.0168	482	407	359		
D	0.0233	292	247	218		
D-1	0.0300	332	280	247		
E	0.0220		460			

In other words the thermal resistance of the jute and compound is neglected, and the effective thermal resistance is that obtained by ***assuming each conductor to transmit heat through only that one-third of its surface which is in contact with the covering.***

Apparently the same idea might be extended to twin conductors. The effective resistance would in that case also be that of the insulation around one conductor and that of the covering over both conductors.

Tests on the Carrying Capacity of Cable E. In order to see how accurately the carrying capacity could be calculated from experimental determinations of μ, an actual test was carried out with cable E.

About 40 feet of the cable were stretched out along the floor, being supported about six inches above the latter by means of blocks at intervals of three feet. The temperature at the copper was determined by means of thermo-couples placed in holes drilled through the insulation. The temperature at the surface was also determined by fastening a couple to the steel braided armor in the manner described above. During the heating, readings were taken on one of the couples at intervals of 5 minutes and from time to time observations were taken at other points along the cable to see that the temperature rise was uniform. The second column in Table V gives the temperature rise at different intervals of time while constant current was passing through the cable. The third column gives the excess of temperature above that of the room at different intervals of time after breaking the current.

TABLE V

Time in minutes	Temperature above that of the room	
	On heating	On cooling
0	0	37.0
5	8.3	28.6
10	13.1	22.1
15	18.1	19.0
20	21	14.3
25	25	12.6
30	26.7	10
35	29.0	7.7
40	30.7	6.1
50	32.9	4.3
55	33.3	3.6
65	34.6	2.1
75	35.2	
95	35.6	
125	37.0	

The heating and cooling curves are plotted in Fig. 1. The heating curve indicates that at the stationary state ($t = \infty$) the temperature rise would have been 38 deg. For a temperature rise of 40 deg. the carrying capacity would therefore be

$$450 \sqrt{\frac{40}{38} \times \frac{1}{1.008}} = 460 \text{ amperes}$$

This agrees very well with the result calculated in Table III, and shows that the indirect *method based on the determination of μ is quite reliable.*

Temperature of the Surface. The ratio of the external resistance (r_e) to the internal thermal resistance (Σr) of the insulation was determined by noting the temperature of the surface. Corresponding to a temperature rise of 38 deg. cent. at the conductor, the temperature of the surface was 23 deg. cent above that of the room. This gives a value for $r_e W$ of 0.6 and agrees very well with the result, 0.59, deduced in Table III.

Rates of Heating and Cooling. The smooth curves drawn through the points on the heating and cooling curves are found to satisfy the equations.

$$\Theta = 38\,(1 - \epsilon^{-0.0425\,t}) \tag{6}$$

and

$$\Theta = 37\epsilon^{-0.046\,t} \tag{7}$$

respectively, where Θ denotes the excess of temperature above that of the room at the time t (in minutes).

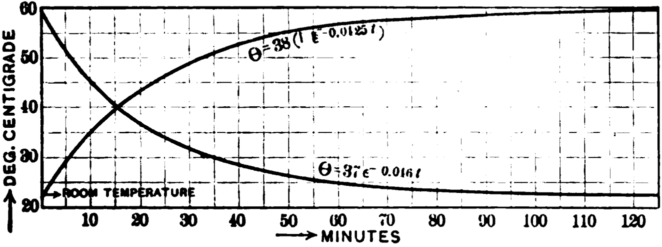

FIG. 1

III. CURRENT CARRYING CAPACITIES OF RUBBER AND VARNISHED CAMBRIC INSULATED CABLES

In the following section the data determined above have been used to calculate the current carrying capacities of the various standard types of cables. The method of calculation is that indicated in equations (1) and (2). In table VI are given the constructional data for rubber insulated cables together with the calculated values of Σr, r_e, W and i, based upon $K = 250$ and $H = 120$.

Table VII gives similar data for varnished cambric insulated cables, braided and leaded. The equations used in the calculations of r and r_e were as follows:

Braided cables $r = 400 \times 0.365 \times \log D/d$
Leaded " $r = 300 \times 0.365 \times \log D_1/d$.

Braided and leaded cables, $r_e = \dfrac{H}{\pi D_2}$

The values of ν, δ and d were obtained from the tables given in *G. E. Bulletin* No. 4787, pages 8 and 9. Data for D, Table VI, were taken from the tables, page 26, while values of D_1 and D_2, Table VII were taken from the table on page 41 (thickness of insulation based on working pressure of 1000 volts).

On page 56 of the same bulletin are given the current carrying capacities from which were taken the figures in the last two colums, Table VI and the last column, Table VII.

In all cases a room temperature of 20 deg. cent. has been assumed, and T = rise in temperature above 20 deg. cent.

DEGREE OF ACCURACY OF CALCULATED CARRYING CAPACITIES

The most important fact brought out in these tables is the *effect of the radiating surface on the carrying capacity of the cable.* Comparing $\Sigma\, r$ and r_e for the same size of cable, it is seen that the thermal resistance of the surface varies in the different cases form 0.50 to 0.87 of the total resistance. In other words the calculated carrying capacity depends more upon the accuracy of H than on that of K.

If the ratio $r_e/\Sigma\, r$ be denoted by n, equation (2) can written be in the form

$$i^2 R_T = \frac{T}{\Sigma\, r\,(n + 1)}$$

Hence, it is readily shown that

$$\frac{\Delta\, i}{i} = -\frac{\Delta\,(\Sigma\, r)}{2\,(n+1)\,(\Sigma\, r)} \tag{8}$$

$$\frac{\Delta\, i}{i} = -\frac{-\,\Delta\,(r_e)}{2\left(1 + \frac{1}{n}\right) r_e} \tag{9}$$

Assuming that on the average $n = 2$, it is seen that a change of 10 per cent, say, in the value of K affects the calculated value of i by no more than 1.6 per cent, whereas a similar change in the value of H, affects the value of i by 3.3 per cent.

Now with regard to the accuracy of the particular values of K and H used in the above calculations, we may assume the limit of error as 15 per cent in the case of K and 10 per cent in the case of H. Consequently the ***possible error in the calculated carrying capacities may be estimated at about* 2.5 *per cent.***

TABLE VI

Carrying capacities of rubber insulated cables (suspended in air). Single conductor, single braid.

Size of cable	ν	δ	S	d	D	$R \times 10^6$	Σr	r_e	W	i for T =			i according to *G. E. Bull.*	i according to *N. E. Code*
										30°C.	20°C.	10°C.		
2,000,000 cir. mils.	127	0.1255	1.57	1.632	1.99	0.449	7.9	19.2	0.0369	1501	1247	898	1400	1050
1,000,000 " "	61	0.1281	0.786	1.153	1.48	0 897	9.9	25.8	0.0289	925	769	554	900	650
500,000 " "	61	0.0906	0.393	0.8154	1.12	1.793	12.6	34.1	0.0214	572	476	342	550	390
250,000 " "	37	0.0823	0.197	0 5754	0.87	3.582	16.4	49.3	0.0166	356	296	213	320	235
0 B. & S.	19	0.0746	0.083	0.3750	0.63	8.507	20.6	60.7	0.0123	199	166	119	165	124
4	7	0.0773	0.033	0.2319	0.42	21.46	23.6	91.0	0.0087	105	88	63	75	64
6	*Solid*		0.0206	0.1620	0.35	34.21	30.6	109.1	0.0072	76	63	45	50	46
10	*Solid*		0.0082	0.1019	0.24	86.40	34.0	159.2	0.0052	41	34	24	20	24

TABLE VII

Carrying capacities of varnished cambric insulated cables (suspended in air). Single conductor, leaded and braided.

Size of cable	Braided							Leaded								i according to G. E. Bull. $T = 60$
	D	Σr	r_e	W	i for T =			D_1	D_2	Σr	r_e	W	i for T =			
					60°C.	40°C.	30°C.						60°C.	40°C.	30°C.	
2,000,000 cir. mils.	2.14	17.3	17.8	0.0285	1775	1497	1318	1.89	2.14	6.9	28.3	0.0284	1773	1496	1317	1750
1,000,000 " "	1.56	19.2	24.5	0.0229	1126	949	836	1.37	1.56	9.4	38.7	0.0208	1073	904	797	1150
500,000 " "	1.19	24.0	32.1	0.0178	703	592	522	1.00	1.19	9.8	50.8	0.0165	676	570	501	660
250,000 " "	0.95	27.6	40.2	0.0139	438	370	326	0.76	0.95	13.2	63.7	0.0130	425	358	315	390
0 B. & S.	0.66	35.9	57.9	0.0107	250	210	185	0.53	0.66	15.6	91.6	0.0093	233	197	173	195
4 B. & S.	0.45	42.2	84.9	0.0079	135	114	100	0.36	0.45	21.0	134.4	0.0064	122	103	91	92
6 B. & S.	0.40	57.6	95.5	0.0065	97	82	72	0.31	0.40	25.7	151.0	0.0057	91	76	67	60

Note: For data on ν, δ, d, S and R consult Table VI.

Representation of Carrying Capacities by a General Formula. Melsom and Booth found that they could express the results obtained by them for the current carrying capacities of rubber and paper insulated cables by an empirical equation of the type

$$\frac{i}{S} = c\left(\frac{D}{S}\right)^{N} \qquad \textbf{(10)}$$

This may be written in the more convenient form:

$$\log\left(\frac{i}{S}\right) = N\log\left(\frac{D}{S}\right) + B^{*} \qquad \textbf{(11)}$$

Where D = outside diameter of cable in inches.
S = cross-section of conductor in square inches.
i = current in amperes.

they obtained the following values for N and B:

TABLE VIII

Constants for calculating carrying capacities of rubber and paper insulated cables according to Melsom and Booth

Type of insulation	N	B for T =		
		11.1 deg.cent.	16.7 deg.cent.	27.7 deg.cent.
Rubber covered in air.	0.616	2.5611	2.6600	
Rubber covered in casing.	0.66	2.4900	2.5539	
Lead covered, paper insulated.	0.50	2.6325	2.7292	2.8376

It is rather remarkable that the same form of equation expresses the results given in Table VI and VII pretty closely.

In Fig. 2 the values of log $\left(\frac{i}{S}\right)$ obtained from Table VI have been plotted as ordinates with corresponding values of log $\left(\frac{D}{S}\right)$ as abscissas. The results given in Table VII for varnished cambric, cotton covered cables have been plotted in a similar manner in Fig. 3. The slope of the line thus obtained in each

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[*] Logarithms to base 10 are of course meant except where otherwise indicated.

case gives the exponent N, while B may be determined either graphically or in the usual manner.

The constants obtained for the three types of insulation tested are given in the following table:

TABLE IX

Constants for calculating carrying capacities of rubber and varnished cambric insulated cables, suspended in air.

Type of insulation	N	B for T =				
		60 deg.	40 deg.	30 deg.	20 deg.	10 deg.
Rubber covered.	0.515			2.93	2.85	2.707
Varnished cambric cotton covered.	0.545	2.985	2.911	2.856		
Varnish cambric lead covered.	0.525	2.975	2.901	2.846		

Table X indicates the good agreement between the values of i calculated from the above interpolation formulæ and the values obtained by the more elaborate calculation given in Tables VI and VII. Denoting the latter by i_1, and those calculated by means of Table IX by i_2, we find that with very few exceptions the two numbers agree to within a couple of per cent.

TABLE X

Values of i_2/i_1

Size of cable	Rubber ($T = 30$ deg.)	Cambric braided ($T = 60$ deg.)	Cambric leaded ($T = 60$ deg.)
2,000,000 cir. mils.	1.007	1.012	0.985
1,000,000 cir. mils.	1.002	0.980	1.050
500,000 cir. mils.	1.003	0.989	0.982
250,000 cir. mils.	1.01	1.022	1.000
0 B. & S.	1.007	0.995	0.996
4 B. & S.	0.983	0.983	1.005
6 B. & S.	0.996	1.030	1.010
10 B. & S.	1.001		

Comparison of Results obtained with Carrying Capacities according to G. E. Bulletin and N.E. Code. In Tables VI and VII are also given the carrying capacities recommended in the *G. E. Bulletin* and those according to the N. E. Code, 1907. From these figures the curves *AA* and *BB*, Fig. 3, and *CC*, Fig. 4, have been plotted. It must, however, be noted that the figures given in the *G. E. Bulletin* are for the cables drawn in ducts, furthermore while the thermal resistances in Table VII have been calculated for a thickness of insulation to be used with a pressure not exceeding

1000 volts, the carrying capacities recommended in the *G. E. Bulletin* are intended to be used for pressures not exceeding 3000 volts.

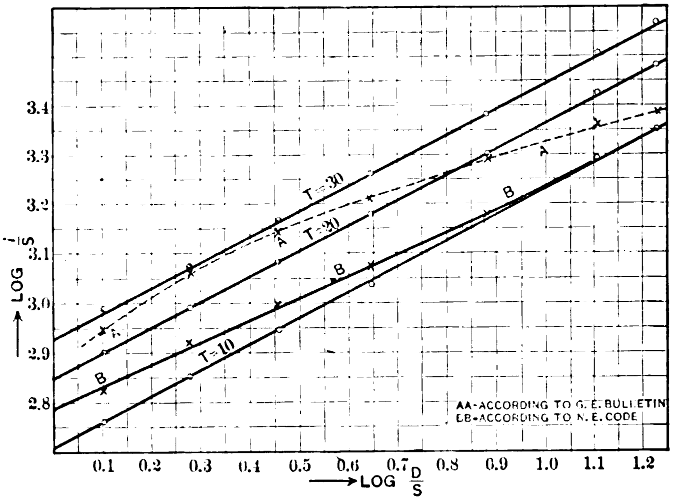

FIG 2.

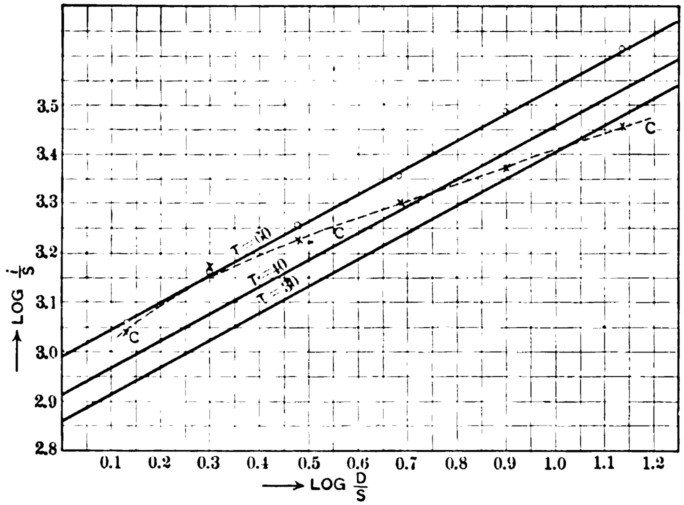

FIG. 3

The calculated carrying capacity is however thereby diminished only one or two per cent, because the effect of increased thickness of insulation is almost neutralized by the effect of increased radiating surface.

It will be noticed that the currents recommended by the N. E. Code are evidently based on $T =$ 15 deg. for large sizes and $T = 10$ deg. for smaller sizes. On the other hand, the carrying capacities recommended in the *G. E. Bulletin* follow a rather irregular law. While for the larger sizes, the currents recommended are nearly equal to those calculated from thermal data, the difference between the two sets of figures becomes greater as the size is diminished. This is indicated even better by calculating the current densities according to the different methods of determing carrying capacity.

TABLE XI

Current density, amperes per sq. in.

Size of cable	Rubber insulation ($T = 30$ deg.)			Varnished cambric insulation $T = 60$ deg.		
	Thermal data	G. E. *Bulletin*	N. E. code	Thermal data		G. E. *Bulletin*
				Braided	Leaded	
2,000,000 C.M.	956	892	669	1130	1129	1114
1,000,000	1177	1124	827	1432	1366	1463
500,000	1455	1400	992	1788	1720	1680
250,000	1807	1624	1193	2223	2158	1980
0 B. & S.	2397	1988	1494	3011	2807	2349
4 B. & S.	3182	2273	1940	4091	3698	2788
6 B. & S.	3690	2428	2233	4709	4417	2913
10 B. & S.	5000	2439	2927			

While it would thus appear as if for certain purposes the current density on the smaller sizes could be increased considerably, it must also be remembered that the temperature rise is not the only factor that has to be considered. Where the necessity arises of keeping the $i\,R$ drop within certain limits, it would be impossible to use such high current densities with smaller sizes of cables, and no doubt such considerations have been largely effective in regard to the figures given in the *G. E. Bulletin.*

Comparison of Results Obtained with those of Melsom and Booth. From the data in Table VIII it is possible to calculate the carrying capacities of rubber and paper insulated cables according to Melsom and Booth.

For rubber covered cables in air, for $T = 10$ deg.

$$\log\left(\frac{i}{S}\right) = 0.616 \log \frac{D}{S} + 2.53 \text{ (Melsom and Booth)}$$

$$= 0.515 \log \frac{D}{S} + 2.707 \text{ (Table IX)}$$

For lead covered cables in air (paper insulated), for $T = 30$ deg.

$$\log \frac{i}{S} = 0.50 \log \frac{D}{S} + 2.860 \text{ (Melsom and Booth)}$$

$$= 0.525 \log \frac{D}{S} + 2.846$$

Table XII gives a comparison of the current densities calculated for different sizes of cable according to both sets of equations.

TABLE XII

Size of cable	D/S	Rubber-covered according to		Lead-covered according to	
		Table IX	M. & B.	Table IX	M. & B.
2,000,000 cir. mils.	1.27	575	392	795	816
500,000 " "	2.85	873	646	1216	1222
0 B. & S.	7.59	1445	1180	2032	1995
6 B. & S.	17.00	2193	1941	3105	2985
10 B. & S.	29.3	2897	2716	4130	3917

On the whole, the two sets of equations give results that are within a couple of per cent for lead-covered cables, but for rubber-covered cables the agreement becomes better only in the smaller sizes.

CALCULATION OF RATES OF HEATING AND COOLING AND CARRYING CAPACITIES UNDER INTERMITTENT USE.

Let q = Rate at which energy is supplied to conductor, in watts per inch.

C = Heat capacity of cable per 1 inch length in watt seconds.

W = Watts transmitted through insulation for 1 deg. difference in temperature, per 1 inch length.

$$\text{Then } q = \frac{C}{60} \frac{d\theta}{dt} + W\theta \text{ [10]} \qquad \textbf{(12)}$$

where θ = temperature rise at the conductor at time t, in minutes.

---

[10] This equation is only approximately true, but the value of b obtained is probably within 10 per cent of the true result.

Integrating **(12)**.

$$\Theta = \frac{q}{W}\{1 - \epsilon^{-bt}\} = T(1 - \epsilon^{-bt}) \tag{13}$$

where $b = 60\ W/C$
and $T = q/W$ = maximum temperature rise.

Hence, it is possible to calculate b, if C and W are known.

Referring to the record of the test on the carrying capacity of cable E, the average value of b determined from heating and cooling curves was found to be 0.044. Since $W = 0.022$, $C = 30$ *watts per second per* 1 *inch length.*

On the other hand, it is possible to calculate C from the heat capacities of the various materials.

Heat Capacities in Watts per Second per inch cube.

Copper	55
Rubber	22.5
Lead	23
Iron (steel)	55

From these data and the thicknesses of the various layers we obtain the value $C = 29$, which is in close agreement with the observed value.

In Table XIII, C has been caclulated for several of the rubber insulated and varnish cambric insulated cables. From the value of C and that of W (Table VI and VII), b has been determined by means of the relation

$$b = \frac{60\ W}{C}$$

From the equation

$$\frac{\theta}{T} = 1 - \epsilon^{-bt} \tag{13a}$$

it is seen that the heating curves of all sizes of cables can be represented by a generalized curve with the equation

$$\frac{\theta}{T} = 1 - \epsilon^{-x}$$

where the *unit of x* is the time in minutes required for the temperature rise to attain 63.21 per cent of its ultimate value; that is, the *unit of time is* $\frac{1}{b}$ minutes.

Such a generalized heating curve is represented in Fig. 4. The four values of x at which θ is 0.5, 0.75, 0.90 and 0.95 respectively of its ultimate value have been indicated on the curve. Similarly the value of x for any other value of $\frac{\theta}{T}$ may be determined from the curve. The cooling curve $\frac{\theta}{T} = \epsilon^{-x}$ has also been plotted with the same units.

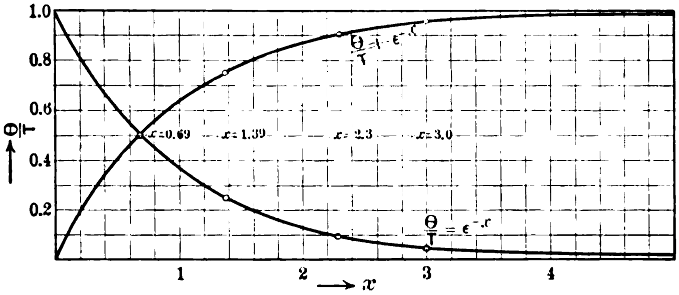

Fig. 4

The use of these curves may be illustrated thus:

If $b = 0.044$, $\frac{1}{b} = 22.73$ minutes. Consequently the intervals of time required for the temperature rise to attain 50,75 and 90 per cent. of its maximum value are 0.69×22.73 (= 16), 1.39×22.73 (= 32) and 2.3×22.73 (= 52) minutes respectively.

In Table XIII are given the values of t (in minutes) at which the cable would attain 50, 75, 90 and 95 per cent of its maximum temperature rise.

TABLE XIII

Size of cable	C	b	t for θ/T = 0.5	0.75	0.9	0.95	D_2	$D_2 b$
Rubber insulated								
2,000,000 cir. mils.	110	0.022	31	63	105	136	2.0	0.044
500,000 " "	32	0.040	17	35	58	75	1.12	0.044
0 B. & S.	9	0.082	8	17	28	37	0.63	0.051
6 B. & S.	2.8	0.15	5	10	15	20	0.35	0.052
Vanished cambric insulated.								
2,000,000 cir. mils.	120	0.014	49	99	164	214	2.14	0.030
500,000 " "	35	0.030	23	46	77	100	1.19	0.036
0 B. & S.	10	0.060	12	23	39	50	0.66	0.039
6 B. & S.	3.3	0.11	6	13	21	27	0.40	0.044

As is seen from the last two columns, the rate of heating (or cooling) varies approximately inversely as the outside diameter for rubber covered cables. This rule does not however extend to varnished cambric insulated cables.

By the use of the graphs in Fig. 4 it is also possible to determine the carrying capacity of the cable when the current is applied only for a short time.

According to equation (**2**)

$$i^2 R_T = T.\ W$$

$$T = \frac{i^2 R}{W} \left(\frac{258 + T}{263}\right) = i^2\, a\, (258 + T) \qquad \textbf{(14)}$$

where $a = \frac{R}{263\ W}$ is a *constant* for any cable.

Now let Θ denote the given rise in temperature which the conductor must not exceed, and t denote the interval of time during which the current is applied. Since b for any cable can be calculated from the heat capacities and thermal resistivities of the materials used in its construction, the value of θ/T for the given value of t can be determined from the graph in Fig. 4.

But

$$\frac{T}{\theta} = i^2 a \left(\frac{258}{\theta} + \frac{T}{\theta}\right) \qquad \textbf{(14}a\textbf{)}$$

Consequently i can be calculated, since Θ and a are constants and $\frac{T}{\theta}$ is known.

The constant a may be determined very conveniently from the values of i given in Tables VI or VII, or more directly from the data for R and W.

The calculation of i for $t = 5$ and $t = 10$ respectively has been carried out in the case of cable E. For this cable, $a = 6.19 \times 10^{-7}$ If we let $\Theta = 40$, we obtain, by means of the value $b = 0.044$,

$$\text{for } t = 5,\ \frac{\theta}{T} = 0.2, \text{ and } i = 840,$$

$$\text{for } t = 10,\ \frac{\theta}{T} = 0.36, \text{ and } i = 697.$$

In this manner curves may be plotted giving the carrying capacity of any cable for a given rise of temperature in terms of the interval of time during which the current is applied.

SUMMARY

The current carrying capacity of an insulated cable may be calculated from data on the thermal resistivity of the insulation and of the surface. It has been shown that these data may be obtained for any type of insulation from experiments on the cable itself by applying a well-known method for determing heat conductivities.

As a result of experiments on different types of cable insulation, the following values have been obtained for the thermal resistivities (deg. cent. per watt per inch cube):

Rubber and cotton braid cover	250
Varnished cambric and cotton braid cover	400
" " (lead-covered cables)	300

For the surface resistivities the following values were obtained (deg. cent. per watt per square inch).

Painted steel braided armor	100
Cotton covering	120
Lead, ordinary	190
" painted dull black	140

These data (which are in agreement with those obtained by other investigators) have been used to calculate the carrying capacities of standard rubber and varnished cambric insulated cables suspended in air. It has been shown that over the range of sizes, No. 10 B. & S. to 2,000,000 cir. mils., the current density (i/s) and the ratio of the outside diameter (D) to the cross-section of the conductor (S) are connected by an equation of the form

$$\log\left(\frac{i}{S}\right) = N \log\left(\frac{D}{S}\right) + B$$

where N is a constant for any type of insulation and B depends upon the temperature rise.

The effect of the surface thermal resistance on the carrying capacity has been shown to be much greater, in general, than that of the intermal thermal resistance. The magnitude of the surface losses is thus of great importance in determining the current carrying capacities of insulated cables.

An approximate method has been worked out for calculating the rates of heating and cooling of insulated cables from the thermal resistances and heat capacities of the materials that enter into the construction of the cables. Furthermore the application has been indicated to the determination of carrying capacities under intermittent use.

In conclusion the author desires to express his appreciation to Dr. I. Langmuir and Mr. W. E. Robinson for their active interest during the progress of the investigation.

COMPARISON OF METHODS OF MAKING LOAD TESTS ON A-C. GENERATORS AND ON INDUCTION MOTORS

BY

E. F. COLLINS and W. E. HOLCOMBE

Presented under the auspices of the

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COMPARISON OF METHODS OF MAKING LOAD TESTS ON A-C. GENERATORS AND ON INDUCTION MOTORS

BY E. F. COLLINS AND W. E. HOLCOMBE

Abstract of Paper

This paper describes the most practical methods that have been employed for obtaining actual load temperatures of alternators and induction motors with an expenditure of power considerably less than that of their rated capacity. These methods are:

Alternators.
1. Zero power factor method,
    - (a) Leading current,
    - (b) Intermittent leading and lagging current.
2. Open- and short-circuit method,
    - (a) Continuous run,
    - (b) Intermittent run.
3. Open delta method.
4. Phase displacement method.

Induction Motors.
1. Feeding-back method.
2. Reduced voltage method.
3. Reversed rotation method.

Data from actual tests are presented to show how closely the temperature rise by these equivalent load methods agrees with that of actual load. No attempt has been made to justify the use of equivalent heating tests through theoretical considerations.

The chief advantages and objections of the different methods are stated and conclusions are drawn as to the most reliable substitute methods for actual load from a practical engineering and commercial point of view.

Certain equivalent tests adapt themselves so well to commercial testing conditions that their use becomes imperative for a large proportion of alternating-current generators and motors.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26–28, 1913.

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COMPARISON OF METHODS OF MAKING LOAD TESTS ON A-C. GENERATORS AND ON INDUCTION MOTORS

BY E. F. COLLINS AND W. E. HOLCOMBE

The object of this paper is to outline briefly some of the most practical methods that have been employed for obtaining the normal running temperatures of alternators and induction motors under no-load or partial load conditions.

Nearly all the methods treated have been discussed in scientific papers at home and abroad and are known to most electrical engineers. It is our intention to speak of these methods only in a general way and to submit data showing comparative results obtained in regular commercial testing.

The chief reasons for testing by these no-load methods are in order that the cost of testing may be materially reduced, and because machines are being built in such numbers and of such capacity that the manufacturer cannot economically provide power supply and testing equipment for the actual loading of all machines.

I. ALTERNATORS

The methods for making heat runs on alternators, with which this paper deals, will be designated as follows:

1. Zero power factor method.
    a. Leading current.
    b. Intermittent leading and lagging current.
2. Open and short-circuit method.
    a. Continuous run.
    b. Intermittent run.
3. Open delta method.
4. Phase displacement method.

1. ZERO POWER FACTOR METHOD

a. *Leading Current.* The machine to be tested is operated as a synchronous motor running free at normal voltage and normal leading current in the armature, obtained by over-exciting the field. As practically the whole armature reaction directly opposes the field the field current is greater than under any other condition of normal armature voltage and current. The normal field heating can, however, be approximated by reducing the observed temperature rise in proportion to the respective field losses.

This method has given very good results and has been extensively used in testing turbo-alternators. The main error of the method is that the field heating will be greater than occurs when operating under full load.

b. *Intermittent Leading and Lagging Current.* The above method is modified by operating the machine alternately for short periods with leading and lagging currents in the armature. The two periods may be adjusted so that the average loss is equal to normal.

Let I_0 be the field current required for over-excitation, I_u the current required for under-excitation, I_n the normal field and X the per cent of a complete cycle (consisting of a period of over-excitation and a period of under-excitation,) during which over-excitation is used, then

$$I_0^2 X + (1 - X) I_u^2 = I_n^2$$

or

$$X = \frac{I_n^2 - I_u^2}{I_0^2 - I_n^2}$$

In this method an attempt is made to compensate for the excessive field heating of the previous case by running the machine intermittently over-excited and under-excited, the time interval to be such as to give normal heating in the field. This method has been found to give excellent results.

The only practical objection to the zero power factor method is that it requires equivalent kv-a. supply, which is not always available.

Tables IA, IB and IC give data comparing results obtained from zero power factor tests with those from actual load on same machine.

TABLE I A

THREE-PHASE, 60 CYCLES, 2500 KV-A., 1800 REV. PER MIN., 2300 VOLTS

Maximum temperature rise	Full load	Zero power factor leading
Armature laminations	35	35
" ducts	31	29
" coils	29	23
" " (res.)	34	27
Field coils (res.)	41	68
" " " reduced to normal	—	42

TABLE I B

*THREE-PHASE, 60 CYCLES, 715 KV-A., 720 REV. PER MIN., 2300 VOLTS

Maximum temperature rise	Full load	Zero power factor leading	Zero power factor Leading 7 min. Lagging 13 min.
Armature laminations	30	36	29
" ducts	23	36	28
" coils	30	35	26
" " (res.)	28	44	30
Field coils	26	54	27
" " reduced to normal	—	19	—
" " (res.)	38	69	38
" " " reduced to normal	—	24	—

TABLE I C

* THREE-PHASE, 60 CYCLES, 257 KV-A., 720 REV. PER MIN., 2530 VOLTS

Maximum temperature rise	Full load	Zero power factor leading	Zero power factor. Leading 3.5 min. Lagging 5.5. min.
Armature laminations	22	22	19
" ducts	20	23	18
" coils	16	20	15
" " (res.)	31	18	23
Field coils	32	77	32
" " reduced to normal	—	36	—
" " (res.)	42	102	44
" " " reduced to normal	—	48	—

* Location of thermometers was the same for these runs

2. Open and Short-Circuit Method

a. *Continuous Run.* This method consists in running the machine a certain percentage above normal voltage on open-circuit until temperatures are constant, then a certain percentage above normal current on short-circuit until temperatures are constant. A maximum rated generator is usually operated at

110 per cent normal volts and 110 per cent normal current, while higher percentages are used with generators that are designed to carry overloads. The core loss when operating above normal voltage is assumed to heat the armature core to approximately the same temperature as it would be heated when operating under normal voltage and current. The $I^2 R$ in the armature coils when running above normal current is assumed to heat the coils to approximately the same temperature as when operating at normal voltage and current.

On open circuit the voltage taken is assumed to be that which would correspond to a core loss equal to the combined armature losses under load. Hence, in the successful application of this method an approximate knowledge of the core loss curve and total armature losses under load is necessary.

Likewise, short-circuit the current is taken a certain percentage above normal. In some cases this current may cause a heating in the coils which is in excess of the heating on full load. On the other hand, on all classes of machines and particularly on machines using forced ventilation, the amount of the cooling air is proportional to the total losses in the machine. With the absence, therefore, of the core loss in armature, which may form a considerable part of the total losses, the heat conduction to a relatively cool core may be more rapid than would be the case were the machine loaded.

Tables IIA, IIB, IIC and IID give data comparing results obtained from the open and short-circuit method (continuous) with those from actual load on the same machines.

b. *Intermittent Run.* The generator to be tested is run alternately open and short-circuited. The length of time for a complete cycle usually varies from four to fifteen minutes.

Let X be the per cent of the time during which the machine is short-circuited, I_c the normal armature current and W_c the normal core loss. When the machine is operated open-circuited, the field current is adjusted to give a voltage such that the core loss is equal to $\frac{W_c}{1 - X}$, and when operated short-circuited, so that the armature current is $\frac{I_a}{\sqrt{X}}$. If I_0 and I_s are the field currents for the periods of open-circuit and short-circuited respectively, and I_n the normal field current, the average field current will be

$$\sqrt{I_s^2 X + I_0^2 (1 - X)}$$

TABLE II A
*THREE-PHASE, 60 CYCLES, 2500 KV-A., 1800 REV. PER MIN., 2300 VOLTS

Maximum temperature rise, deg. cent	*Full load	Open-circuit 110 per cent volts	Short-circuit 120 per cent amperes
Armature laminations	35	36	—
" ducts	31	28	—
" coils (thermo.)	29	—	35
" " (res.)	34	—	45
Field winding	41	48	—

* Average of runs on two similar machines.

TABLE II B
THREE-PHASE, 33 CYCLES, 5400 KV-A., 1990 REV. PER MIN., 2300 VOLTS

Maximum temperature rise	Full load	Open-circuit 110 per cent volts	Short-circuit 122 per cent amperes
Armature laminations	25	20	—
" ducts	24	16	—
" coils	22	—	34
Field winding (res.)	38	25	—

TABLE II C
†THREE-PHASE, 60 CYCLES, 715 KV-A., 720 REV. PER MIN., 2300 VOLTS

Maximum temperature rise	Full load	Open-circuit 110 per cent volts	Short-circuit 110 per cent amperes
Armature laminations	30	25	—
" ducts	23	24	—
" coils	30	—	30
" " (res.)	28	—	32
Field coils	26	21	—
" " (res.)	38	35	—

† Thermometers were in the same location for all runs.

TABLE II D
THREE-PHASE, 60 CYCLES, 3000 KV-A., 514 REV. PER MIN., 2300 VOLTS

Maximum temperature rise	Full load	Open-circuit 110 per cent volts	Short-circuit 125 per cent amperes
Armature laminations	32	30	—
" ducts	29	24	—
" coils	25	—	24
" " (res.)	34	—	30
Field coils	21	29	—
" " "	21	29	—

the value of X being so chosen that the average field current will be equal to I_n. If this is done, the average losses due to armature current, core loss and field excitation should be about the same as under load. It is not always possible to choose a value for X that will make the average field loss equal to the normal field loss, but the field heating can be approximated.

In some generators the short-circuit core loss is considerable and cannot be neglected. This can be taken care of by slightly modifying the intermittent method.

If W_s be the short-circuit core loss corresponding to armature current $\frac{I_a}{\sqrt{X}}$, used during period of short-circuit, the total loss supplied during interval X will be $W_s X$. This loss should be subtracted from the normal core loss to find the core loss to be supplied during the period of open circuit. This loss will be

$$\frac{Wc - Ws X}{1 - X} \text{ instead of } \frac{Wc}{1 - X}$$

Several tests have been made by this method and the temperatures obtained agree fairly well with load temperatures. In the practical application of this method judgment should be exercised in selecting periods obtained by the foregoing formula so that the armature winding may be not subjected to excessive currents that result in damage to insulation before a dangerous temperature is recorded on a thermometer applied to the external surface.

This test requires a knowledge of both the open and short-circuit core loss before the run is begun, which sometimes handicaps its use.

Tables IIE, IIF and IIG give data comparing results obtained from the intermittent open and short-circuit method with those from actual load on the same machines.

3. Open Delta Method

The armature winding of a three-phase machine is connected in delta with one corner open and direct current is introduced at this point. The fields are excited with that current which gives normal volts when the machine is operating under full load. The excitation is calculated from the saturation and impedance curves.

In many machines an alternating cross current may flow in the delta due to the harmonics. When this current exists it is measured and combined vectorially with the applied direct-current value. The proper value of the current to give armature copper loss corresponding to normal load current (I_a) will be equal to

TABLE II E
THREE-PHASE, 60 CYCLES, 2500 KV-A., 1800 REV. PER MIN., 2300 VOLTS

Maximum temperature rise	Full load	Intermittent run Open-circuit 10 min. 117 per cent volts short-circuit 5 " 173 per cent amperes
Armature laminations	36	32
" ducts	31	29
" coils	29	17
" " (res.)	34	22
Field " "	41	37

TABLE II F
*THREE-PHASE, 60 CYCLES, 715 KV-A., 720 REV. PER MIN., 2300 VOLTS

Maximum temperature rise	Full load	Intermittent run 7.5 min. open-circuit 116 per cent volts. 7.5 " short-circuit 143 per cent amp's.
Armature laminations	30	29
" ducts	23	30
" coils	30	40
" " (res.)	28	40
Field "	26	25
" " (res.)	38	34

* Location of thermometers the same for both tests.

TABLE II G
* THREE-PHASE, 60 CYCLES, 257 KV-A., 720 REV. PER MIN., 2530 VOLTS

Maximum temperature rise	Full load	Intermittent run 4 min. short-circuit 152 per cent amp's. 5.5 " open- " 113 per cent volts
Armature laminations	22	19
" ducts	20	18
" coils	16	15
" " (res.)	31	23
Field "	32	32
" " (res.)	42	44

* Thermometers in same position for both runs.

$I_d = \sqrt{I^2_a - I^2_c}$ where I_d equals the applied direct current and I_c equals the circulating current due to the harmonics.

This method may be used on other than three-phase alternators by properly splitting and connecting the stator windings so as to obtain zero or a low potential across the opening into which the direct current is introduced.

Satisfactory results have been obtained in some cases by this method, but it is unreliable for general testing. This is largely due to the fact that the direct current in the armature forms a magnetic pole out of each group of coils per phase which results in a pulsating flux and abnormal losses.

TABLE III A
* THREE-PHASE, 60 CYCLES, 715 KV-A., 720 REV. PER MIN., 2300 VOLTS
SALIENT POLE MACHINE

Maximum temperature rise	Full load	Open delta
Armature laminations	30	29
" ducts	23	25
" coils	30	25
" " (res.)	28	26
Field "	26	21
" " (res.)	38	32

* Location of thermometers the same for both runs.

TABLE III B
THREE-PHASE, 60 CYCLES, 2500 KV-A., 1800 REV. PER MIN., 2300 VOLTS
NON-SALIENT POLE MACHINE

Maximum temperature rise	†Full load	Open delta
Armature laminations	35	51
" ducts	31	53
" coils	29	37
" " (res.)	34	45
Field " "	41	108

† Average of two similar machines.

TABLE III C
THREE-PHASE, 60 CYCLES, 300 KV-A., 1800 REV. PER MIN., 480 VOLTS
NON-SALIENT POLE MACHINE

Maximum temperature rise	Full load	Open delta
Armature laminations	25	31
" ducts	22	27
" coils	21	27
" " (res.)	38	33
Field " "	19	41

Tables IIIA, IIIB and IIIC give data comparing results obtained from the open delta method with those from actual load on the same machines.

4. Phase Displacement Method

Duplicate generators are assembled with their fields coupled together in such a way that a displacement of phases may be obtained by shifting one field with respect to the other or by shifting armature frames. A direct-current motor of sufficient capacity to take care of the losses in both machines is used to drive the generators at normal speed. The required condition of load and power factor must be obtained by trial. The stators are connected together electrically for proper phase rotation so that one machine acts as the motor and the other as the generator.

This method will give results in all cases indentical with those obtained under actual load.

TABLE IV
THREE-PHASE, 60 CYCLES, 2500 KV-A., 1800 REV. PER MIN., 2300 VOLTS
TEMPERATURE RISES, DEG. CENT.

	1	2	3	4	5	6
Armature laminations	35	35	51	36	—	32
" ducts	31	29	53	28	—	29
" coils (ther.)	29	—	37	—	35	17
" " (res.)	34	27	45	—	45	22
Field winding (res.)	41	68	108	48	—	37
" " corrected	—	42	—	—	—	—
Room	24	19	24	30	31	27

Column 1. Average of two runs on similar machines, 100 per cent power factor, actual load.
Column 2. Zero power factor method, over-excited field.
Column 3. Open delta method.
Column 4. Open-circuit run at 110 per cent normal volts.
Column 5. Short-circuit run at 120 per cent normal amperes.
Column 6. Intermittent run: open-circuit 10 min., 117 per cent volts; short-circuit 5 min., 173 per cent amperes; repeated until temperatures were constant.

The principal objection to this method is that it requires two identical machines, and may be used only when it is possible and practical to couple them together.

Tables IV and V show comparative temperatures obtained on the same machine run in accordance with the serveral methods described.

The temperatures recorded for the 715-kv-a. machine were obtained during successive runs and the thermometers on the machine were not disturbed during the entire progress of the tests The rotating parts were also marked so that the thermometers were always applied to the same points when machine was shut down.

TABLE V
THREE-PHASE, 60 CYCLES, 715 KV-A., 720 REV. PER MIN., 2300 VOLTS
TEMPERATURE RISES, DEG. CENT.

	1	2	3	4	5	6	7	8	9
Armature core lam. (max.)	30	32	36	29	38	25	29	35	29
" " " (av.)	29	31	34	28	36	23	28	33	28
Armature core ducts (max.)	23	34	36	28	37	24	30	36	25
" " " (av.)	22	29	32	26	35	23	27	31	23
Armature coils (max.)	30	30	35	26	37	30	40	51	25
" " (av.)	25	27	32	23	36	27	34	42	23
Armature coils res. (max.)	28	37	44	30	46	32	40	47	26
" " " (av.)	28	37	44	30	46	32	40	47	—
Field spiders (max.)	18	22	27	17	28	16	18	24	19
" " (av.)	18	21	27	17	27	15	17	23	19
Collector rings (max.)	18	16	30	19	32	23	20	20	12
" " (av.)	17	15	28	18	31	21	20	19	12
Pole tip lead (max.)	23	27	34	19	31	17	20	29	22
" " " (av.)	22	26	33	19	31	17	20	28	22
Pole tip trail (max.)	23	27	33	20	28	16	20	32	22
" " " (av.)	22	26	32	20	27	16	19	29	22
Bridges (max.)	24	28	57	19	31	22	23	36	20
" (av.)	24	27	51	19	29	20	22	32	20
Squirrel cage (max.)	18	20	20	15	25	12	16	26	15
" " (av.)	18	19	20	14	23	12	16	23	15
Spools (max.)	26	45	59	22	31	21	25	42	21
" (av)	26	35	54	21	30	21	23	39	21
Spools by resistance*	38	50	69	38	59	35	34	59	32
" " " †	22	37	60	24	32	23	25	36	24
Frame (max.)	17	18	19	16	21	14	16	20	16
" (av.)	17	17	19	16	21	13	16	19	15
Room (max.)	20	23	21	19	21/23	25/22	22	21	18
" (av.)	20	23	21	19	—	25	22	22	—

* Resistance by voltmeter and ammeter.

† Resistance by galvanometer.

Column 1. Machine running as a motor, full load, 100 per cent power factor.

Column 2. Full load, 80 per cent power factor, leading.

Column 3. Zero power factor method with field over-excited to give full load current in armature.

Column 4. Zero power factor method over-excited 7 min. and under-excited 13 min., except during last hour of run, when periods were changed to 3½ min. over-excited and 6½ min. under-excited.

Column 5. Sum of temperatures from open- and short-circuited runs at normal voltage and normal current.

Column 6. Temperatures from open-circuit run at 110 per cent volts for the iron parts and field, and from short-circuit run at 110 per cent current for armature coils.

Column 7. Intermittent run, 7.5 min. open-circuit at 116 per cent volts and 7.5 min. short-circuit 143 per cent amperes.

Column 8. Intermittent run, open- and short-circuited with periods determined from excitation for 80 per cent power factor condition, 5 min. open-circuit at 140 per cent. volts and 10 min. short-circuit at 130 per cent amperes.

Column 9. Open delta method.

CONCLUSIONS

We believe the zero power factor method with intermittent leading and lagging current to be the best substitute for full load test since the losses have approximately the same distribution as exist in the machine under load. This conclusion is confirmed by the results of the foregoing temperature tests. The zero power factor method with leading current gives practically the same values, with the exception of greater heating on the field. This can be readily corrected for normal field loss.

The open- and short-circuit method has been extensively used and when proper values of voltage and current are chosen will give results agreeing fairly well with actual load values. It is primarily recommended as a checking test on machines whose temperatures have previously been determined by the zero power factor or actual load methods, and whenever it is not practical or convenient to use these methods.

II TEMPERATURE TESTS WHICH APPROXIMATE ACTUAL LOAD CONDITIONS FOR INDUCTION MOTORS

The methods described are as follows:

1. Feeding-back method.
2. Reduced voltage method.
3. Reversed rotation method.

1. FEEDING-BACK METHOD

This test is made by belting together two induction motors, in such a manner as to make one run above and the other below synchronous speed. The amount that each differs from synchronous speed is the normal slip for that load. The stators are connected in multiple to an a-c. supply of normal frequency and voltage.

One machine acts as a generator and the other as a motor. Temperatures obtained on the motor under these conditions of load will equal normal operating temperatures.

This method involves difficulties in obtaining proper pulley diameter and is limited by the power that is readily transmitted by belting.

Where the induction motor is direct-connected to a d-c. machine and two sets are available, the feeding-back method may be used in all cases and temperatures will be obtained equivalent to those of full load.

2. Reduced Voltage Method

This test is made by running the motor free at normal volts until temperatures are constant. The motor is then operated at a reduced voltage and sufficient load to give the required current. The kv-a. input is usually $\frac{1}{4}$ to $\frac{1}{2}$ of normal and the power output about 1/16 to $\frac{1}{4}$ of normal. Although the load carried at reduced voltage is small, the slip from synchronous speed exceeds that for the same primary current at normal voltage. Full load speed is desirable and is obtained by raising the frequency of supply a small percentage.

The temperature rise on the stator at full load may be determined from the above method as follows:

T_f = Temperature rise on stator for full-load normal volts.
T_n = Temperature rise on stator for no-load normal volts.
T_r = Temperature rise on stator for reduced voltage run.
E_n = Normal voltage.
E_r = Reduced voltage.

$$T_f = T_r - \frac{T_n E_r^2}{E_n^2} + T_n$$

The same method of calculation may be followed for any load. The rotor temperature is to be taken as observed on reduced voltage run. As a rule, the calculated temperature rises from this method are somewhat greater than those obtained from actual load.

Tables VI, VII, VIII, IX and X give data comparing temperatures from actual load with temperatures obtained by the reduced voltage method.

TABLE VI

THREE-PHASE, 60 CYCLES, 20 H.P., 1200 REV. PER MIN., 220 VOLTS

Maximum temperature rise in deg. cent.	Full load	Normal amperes 80 volts	Running free at normal volts	Corrected for full load	125 per cent load	125 per cent normal amperes 80 volts	Corrected for 125 per cent load
Stator laminations..	25	20	14	32	33	27	39
" ducts.......	20	17	8	24	28	23	30
" coils........	20	18	7	23	27	25	30
" " (res.)....	25	—	10	—	30	—	—
Rotor conductors...	18	18	6	18	25	20	20

TABLE VII
* THREE-PHASE, 60 CYCLES, 20 H.P., 1200 REV. PER MIN., 220 VOLTS

Maximum temperature rise	Full load	Normal current 80 volts	Running free at normal volts	Corrected for full load	125 per cent full load	125 per cent current 90 volts	Corrected for 125 per cent load
Stator laminations..	22	19	15	32	29	29	41
• ducts.......	19	16	10	25	29	23	31
• coils........	16?	21	12	31	27	27	37
• • (res.)...	25	26	16	40	35	33	46
Rotor conductors...	15	16	11	16	22	23	23

* Location of thermometers not changed during run.

TABLE VIII
THREE-PHASE, 60 CYCLES, 50 H.P., 900 REV. PER MIN., 440 VOLTS

Maximum temperature rise	Full load	Normal amperes 220 volts	Running free at normal volts	Corrected for full load
Stator laminations..............	24	19	10	26
• ducts.....................	16	12	4	15
• coils......................	18	14	6	18
• • (res.)................	32	23	22	39
Rotor conductors...............	17	18	6	18

TABLE IX
* THREE-PHASE, 60 CYCLES, 100 H.P., 720 REV. PER MIN., 550 VOLTS

Maximum temperature rise	Full load	Normal current 156 volts	Running free at normal volts	Corrected for full load	125 per cent full load	125 per cent current 238 volts	Corrected for 125 per cent load
Stator laminations..	24	15	12	26	34	24	34
• ducts.......	20	14	9	22	25	22	32
• coils........	23	14	7	20	30	25	31
• • (res.)....	29	16	9	24	31	27	35
Rotor conductors....	16	7	5	7	24	18	18

* Location of thermometers not changed during runs.

TABLE X

* THREE-PHASE, 60 CYCLES, 250 H.P., 600 REV. PER MIN., 440 VOLTS

Maximum temperature rise	Full load	Normal amperes 130 volts	Running free at normal volts	Corrected for full load	125 per cent amperes	165 volts	Corrected for 125 per cent load
Stator laminations..	22	21	10	30	33	32	40
" ducts.......	21	17	7	23	30	30	36
" coils.......	21	19	6	24	29	31	36
" " (res.)....	23	18	10	27	33	31	39
Rotor conductors...	20	20	5	20	23	33	33

* Location of thermometers not changed during runs.

3. REVERSED ROTATION METHOD

This test is made by driving the rotor at normal full-load speed in a direction opposite to that in which it has a tendency to turn when current is applied to the stator. The impressed volts on stator are adjusted to give the current corresponding to any load.

This method appears to be a practical one and gives temperature rise on the stator in most cases that very closely approach normal running temperatures. It is difficult, however, to completely explain why the temperatures obtained are in such close agreement with those obtained under actual load.

Tables XI, XII and XIII give data comparing temperatures from actual load with those obtained by this method.

TABLE XI

* THREE-PHASE, 60 CYCLES, 250 H.P., 600 REV. PER MIN., 440 VOLTS

Maximum temperature rise	Full load	Reversed rotation normal amperes	125 per cent load	Reversed rotation 125 per cent amperes
Stator laminations........	22	19	33	31
" ducts.............	21	17	30	27
" coils..............	21	19	29	34
Rotor conductors.........	20	15	23	22

* Location of thermometers same for all runs.

TABLE XII

* THREE-PHASE, 60 CYCLES, 100 H.P., 720 REV. PER MIN., 550 VOLTS

Maximum temperature rise	Full load	Normal amperes reversed rotation
Stator laminations............	24	23
" ducts..................	20	20
" coils..................	23	25
" " (res.)...............	29	30
Rotor conductors..............	16	18

* Location of thermometers same for all runs.

TABLE XIII

*THREE-PHASE, 60 CYCLES, 20 H.P., 1200 REV. PER MIN., 220 VOLTS

Maximum temperature rise	Full load	Normal amperes reversed rotation	125 per cent load	125 per cent amperes reversed rotation
Stator laminations	25	18	33	26
" ducts	20	18	28	24
" coils	20	17	27	23
" " (res.)	25	18	30	26
Rotor conductors	18	17	25	23

* Location of thermometers same for all runs.

From the data presented it will be noted that both the reduced voltage and reversed rotation methods give temperatures closely approximating those obtained under actual load. The distribution of losses in the machine under the reduced voltage method is more nearly normal than in the reversed rotation method. Either method is easily applied and requires the expenditure of only a small amount of power compared with the rated output of the motor under test.

POTENTIAL WAVES OF ALTERNATING-CURRENT GENERATORS

BY

W. J. FOSTER

Presented under the auspices of the

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POTENTIAL WAVES OF ALTERNATING-CURRENT GENERATORS

BY W. J. FOSTER

Abstract of Paper

The author states his purpose to be three-fold:

1. To discuss briefly certain elements in design that affect the character of the potential wave;
2. To show the effect of load and operating conditions on the no-load wave;
3. To give illustrations of the potential waves,—good, bad and indifferent, of generators, that actually supply the a-c. systems throughout the country.

There are ninety illustrations in all; a study of these shows, in connection with the descriptions given, that the most perfect wave is obtained where the proper shading of the magnetic flux is obtained either by shaping the poles, in the case of definite pole machines, or the proper distribution of field winding, in the case of cylindrical rotor machines, together with an irregular, or more or less prime relation between the number of slots in the armature and number of poles.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26-28, 1913

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(*Subject to final revision for the Transactions.*)

POTENTIAL WAVES OF ALTERNATING-CURRENT GENERATORS

BY W. J. FOSTER

It is not the purpose of this paper to discuss pro and con the advisability of building generators that develop "a sine wave under all conditions of load," as sometimes stipulated in specifications. Suffice it to say that designers and users of alternating-current generators have been content up to the present time with simply a rough approximation to a sine wave.

The purpose of this paper may be said to be three-fold; first, to show some potential waves that have more or less close relation to the evolution of a-c. generators; second, to show how load and other conditions affect the no-load or open-circuit wave; third, to exhibit waves of several generators that have supplied commercial systems, large and small, for many years.

The exhibit, for the most part, pertains to generators that have open slots in the armature and form-wound coils.

In connection with definite pole generators of high periodicity and high voltage, and at the same time of small capacity, or more exactly, small capacity per pole, it is of great importance that poles shall be so shaped that there shall be a sinusoidal distribution of flux in the air gap. The three waves, curves 1, 2 and 3, showing the potential as affected by shape of pole, were taken many years ago during a study of the problem. The machine was a 60-cycle, 150-kw., 6600-volt, three-phase, belt-driven generator which happened to be available for the purpose. The only changes made were on the pole faces. It is probable that a better wave could have been obtained by an additional trial.

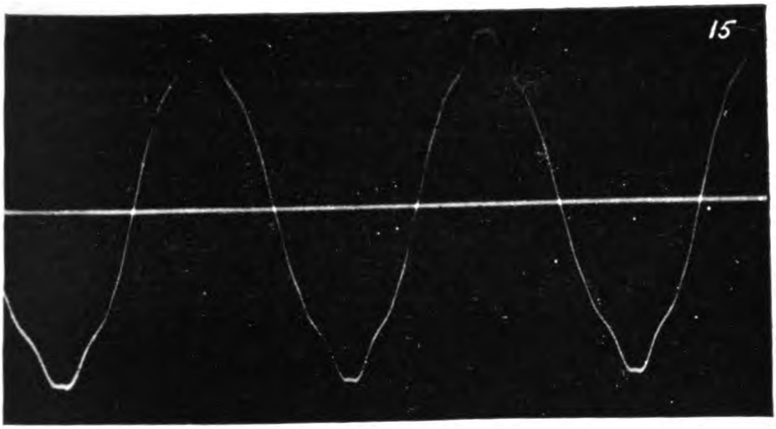
Curves 4 and 5 show what was accomplished on another alternator by a slight change in the curvature of the pole face, *viz.*, a reduction from 8¼ in. (21 cm.) to 7¾ in. (19.6 cm.), of the radius to which poles were turned.

Assuming a pole of proper shape, the fundamental of the potential wave becomes a sine. The problem is then to reduce the harmonics to a minimum. Curves 6, 7 and 8 give typical curves of one slot, two slots and three slots, respectively, per phase per pole for star-connected, three-phase, high-voltage generators. These show plainly harmonics that are caused by the slots in armature. The harmonics due directly to the slots are never lower than of the fifth order in commercial generators, since there are three slots per pole in a one slot per pole per phase, three-phase machine. It is the third harmonic, more especially, that needs to be reckoned with in laying out armature windings. If the wave across each phase itself were a perfect sine with no harmonics, the wave from terminal to neutral in star-connected would be indentical with that across terminals, and also with the delta-connected. Few commercial machines approximate this ideal condition.

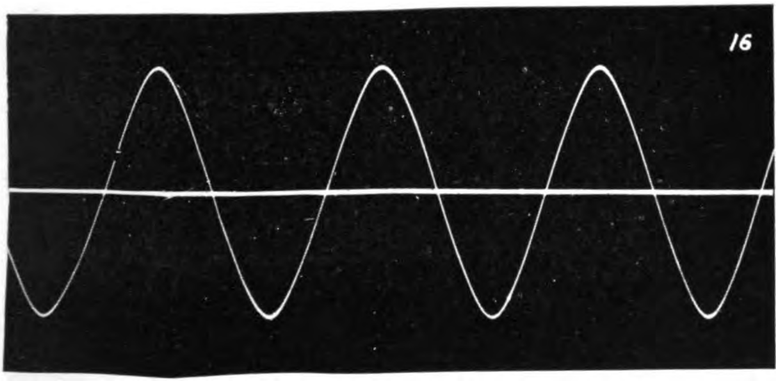
Curve 9 is an example of a poor wave, due largely to the circulating third harmonic current in the closed delta. Curve 10 is taken across the delta when opened at one corner. The wave would be poor on this generator if star-connected. Curve 11 may be taken as representative of a large number of delta-connected commercial generators which have quite good wavse when star-connected. Curve 12 shows the possibilities in a delta-connected armature. This belongs to a five slot per phase per pole generator with large air gap and nicely shaped pole.

Sometimes in star-connected machines the wave across one phase or between terminal and neutral is broad topped as compared with that across two phases or between terminals, (see curves 13 and 14,) in other cases the converse is true.

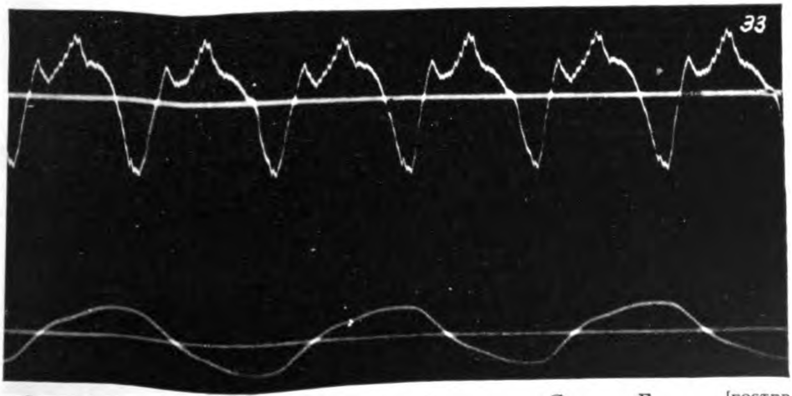
It is evident that the harmonics and, consequently, the resultant or completed wave, will be modified by varying the pitch of the armature winding or by staggering the poles, or by an irregular spacing of the poles. Equally good results have been obtained by making the number of slots in the armature not an exact multiple of the product of poles by phases—a construction much preferable to diagonalling the poles, when considered from the standpoint of mechanical design. A vernier effect is thus established between the armature and the field. This design might be designated the "hunting tooth." Curve 16



CURVE 15.—POTENTIAL WAVE, NO LOAD. [FOSTER]
150 kv-a., 60-cycles, three-phase generator, one slot per phase per pole.



CURVE 16.—POTENTIAL WAVE NO LOAD [FOSTER]
150 kv-a., 60-cycle, three-phase generator, 1½ slots per phase per pole.



CURVE 33.—POTENTIAL WAVE ON EXPLORING COIL IN FIELD. [FOSTER]
800-kv-a., 25-cycle, 3300-volt generator carrying single-phase load.

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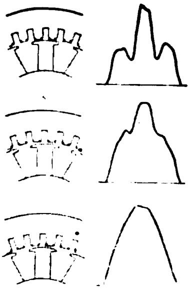
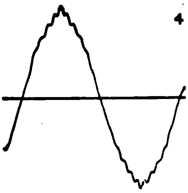
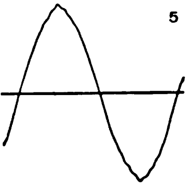


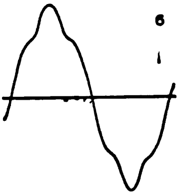
CURVES 1, 2 AND 3.—WAVE FORMS AT NO-LOAD AS AFFECTED BY SHAPE OF POLE.



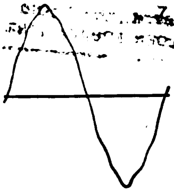
CURVE 4.—POTENTIAL WAVE—NO LOAD.
18 kv-a., 25 cycle, 750 rev. per. min., three-phase, 110 volts, pole face 8½ in. radius.



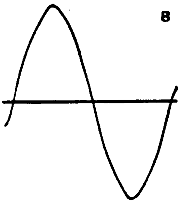
CURVE 5.—POTENTIAL WAVE—NO LOAD.
18 kv-a., 25 cycles, 750 rev. per. min., three-phase, 110 volts, pole face 7¾ in. radius.



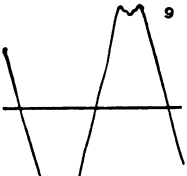
CURVE 6.—POTENTIAL WAVE—NO LOAD.
Three-phase-star connected—one slot per phase per pole, 3000 kv-a., 60 cycle, 6600 volts.



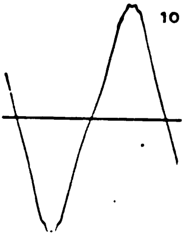
CURVE 7.—POTENTIAL WAVE—NO LOAD.
Three-phase, star connected, two slots per phase per pole, 2700 kv-a., 35 cycle, 13200 volts.



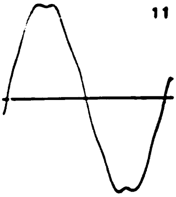
CURVE 8.—POTENTIAL WAVE—NO LOAD.
Three-phase star connected, three slots per phase per pole, 2700 kv-a., 60 cycle, 6600 volts.



CURVE 9. — POTENTIAL WAVE—NO LOAD, ACROSS TWO TERMINALS OF A DELTA CONNECTION.
4200 kv-a., 60 cycle, 720 rev. per. min., three-phase, 2300 volts.



CURVE 10.—POTENTIAL WAVE—NO LOAD ACROSS SAME TERMINALS AS IN FIG. 9 BUT WITH OPEN DELTA.
4200 kv-a., 60 cycle, 720 rev. per. min., three-phase, 2300 volts.



CURVE 11.—POTENTIAL WAVE—NO LOAD —DELTA CONNECTED
900 kv-a., 25 cycles, 150 rev. per. min., three-phase, 400 volts.

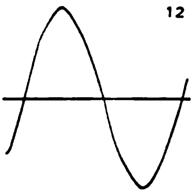
compared with 15 shows what may be accomplished by this scheme. There is no other difference between the two generators to affect the wave except the slot ratio. Curve 17 is another illustration of the good results that have been obtained in this way.

It has been the general practise to connect armature windings indiscriminately star or delta, except in certain designs where the third harmonic is too pronounced. Curves 18 and 19 superimposed, show at a glance the differences that existed in connection with one of the earlier steam-turbine generators that was standard for several years. It is sometimes advisable, when testing a delta-connected armature of a new design, to open a corner of the delta and insert an ammeter to measure the circulating current, or take an e.m.f. wave across the open corner. Curves 20 and 21 are oscillograph records of investigations made on a cylindrical rotor with distributed field winding. Incidentally, these records show the influence of the third harmonic current, when flowing in the closed delta, on the potential wave of the fundamental itself.

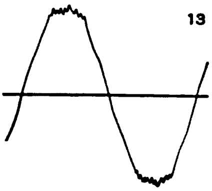
The star-connected generators are not immune from third harmonic trouble in case the neutrals of generators differing in potential wave are grounded without resistance, or with very little resistance. Curves 22 and 23, superimposed for easier comparison, are of 7,000- and 11,000-kv-a. generators, respectively, in connection with which the current to ground was so large as to overload the armature windings and make parallel operation impossible with both neutrals direct to ground.

Potential waves are often modified, both under load and no-load conditions, by circulating currents in the pole faces or in amortisseur windings on the field. Curve 24 shows a wave taken on a 13,200-volt synchronous motor with broad open slots, rather small air gap and squirrel-cage winding on the field where the spacing of the bars in the poles was too close to that of the slots in the armature. Curve 25 is the wave with the squirrel-cage winding removed. Curve 26 is the wave with squirrel-cage winding in place and magnetic wedges in the armature slots. Unfortunately this wave had to be taken at about three-fourths voltage, on account of the heat generated in the wedges at voltages approaching the normal. Curves 27 and 28 are examples of good waves of synchronous motors with squirrel-cage windings.

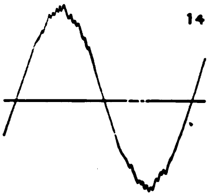
Potential waves taken anywhere that differences of potential



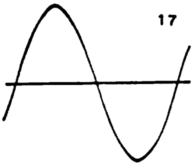
Curve 12.—Potential Wave—No Load.
Delta connected, 6000 kv-a., 50 cycles, 250 rev. per. min., three-phase. 2300 volts, long distance transmission in system of 30,000 kw.



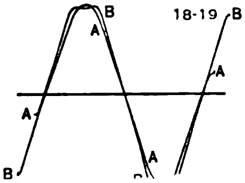
Curve 13.—Potential Wave—No Load across One-Phase.
2400 kv-a., 60 cycles, 360 rev. per. min., three-phase, 11000 volts. (Amortisseur windings).



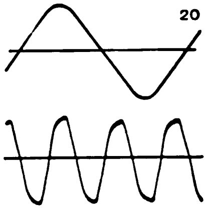
Curve 14.—Potential Wave—No Load, across Two Phases.
2400 kv-a., 60 cycles, 360 rev. per. min., three-phase, 11000 volts. (Amortisseur windings.)



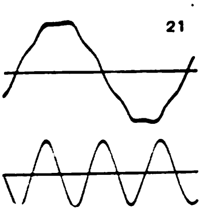
Curve 17.—Potential Wave—No Load.
8400 kv-a., 50 cycles, three-phase, 11000 volts, 3½ slots per phase per pole.



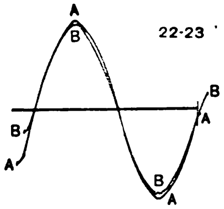
Curves 18 and 19.—Potential Waves—No Load
No. 18—Curve A, Star connected. No. 19—Curve B, Delta connected 2100 kv-a., 60 cycle, three-phase, generator.



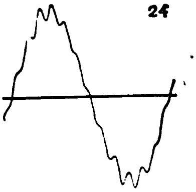
Curve 20 — Oscillograms—No Load, Open Delta.
Upper Curve, Potential across one phase. Lower Curve, Potential across open delta. 1250 kv-a., 60 cycles, 4000 volts.



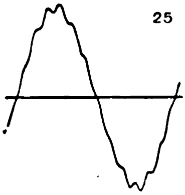
Curve 21. — Oscillograms—No Load, Closed Delta.
Upper Curve, Potential across one phase. Lower Curve, Potential across closed delta. 1250 kv-a., 60 cycles, 4000 volts.



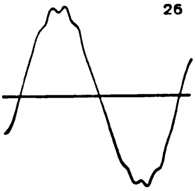
Curves 22 and 23.—Potential Waves No Load
Two generators with neutrals gounded, three-phase, 25 cycles, 9000 volts. A, 7000 kv-a., B, 11000 kv-a.



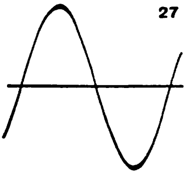
Curve 24.—Potential Wave—No Load.
700 kv-a., 60 cycles, synchronous motor, squirrel cage windings, three-phase, 13200 volts.



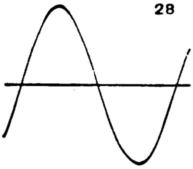
CURVE 25.—POTENTIAL WAVE NO LOAD.
700 kv-a., 60 cycle, synchronous motor, squirrel cage removed, three-phase, 13200 volts.



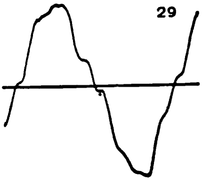
CURVE 26.—POTENTIAL WAVE NO LOAD AT 9500 VOLTS.
700 kv-a., 60 cycle, synchronous motor, squirrel cage winding three-phase, 13200 volts, magnetic wedges.



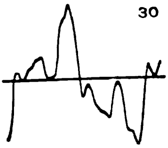
CURVE 27.—POTENTIAL WAVE—NO LOAD
90 kv-a., 60 cycles, synchronous motor, with squirrel cage winding, three-phase, 220 volts.



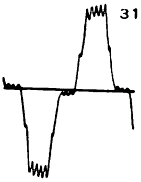
CURVE 28.—POTENTIAL WAVE — NO LOAD.
450 kv-a., 60 cycles, synchronous motor, three-phase, 480 volts, squirrel cage winding.



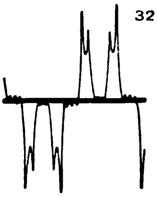
CURVE 29.—POTENTIAL WAVE BETWEEN SHAFT AND BEARING.
4500 kv-a., 25 cycle, 2200 volt, two-phase, generator.



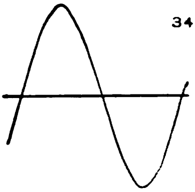
CURVE 30.—CURRENT WAVE BETWEEN SHAFT AND BEARING.
9375 kv-a., 60 cycles, three-phase, 5000 volts.



CURVE 31 —POTENTIAL WAVE ON EXPLORING COIL, SPANNING 12 TEETH — FULL POLE PITCH.
1400 kv-a., 50 cycles, three-phase, 10,000 volts.



CURVE 32.—POTENTIAL WAVE ON EXPLORING COIL, SPANNING 1 TOOTH OF 12 SLOTS PER POLE.
1400 kv-a., 50 cycles, three-phase, 10000 volts.

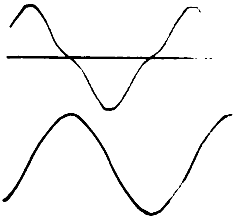


CURVE 34.—POTENTIAL WAVE — FULL LOAD UNITY POWER FACTOR.
18 kv-a., 25 cycle, 750 rev. per min., three-phase, 110 volts,—pole face 7¾ in. radius.

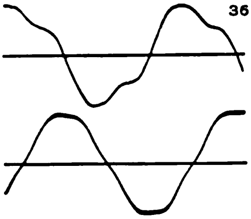
are found to exist are often useful, as are those on special coils made for the purpose. Curve 29 shows potential between shaft and bearing, where currents in the bearings were causing injury. Curve 30 shows current wave on a different machine. Curve 31 is the potential across a special exploring coil located in slots an exact pole pitch apart, or spanning 12 teeth. Curve 32 is the potential between two adjacent slots as determined by a special coil wound around one tooth in the same 12 slots per pole armature. Curve 33 is potential on a special coil located in the innermost slots of a cylindrical rotor (field) of a steam-turbine generator when carrying the single-phase load, and shows the double frequency e.m.f. induced in the field when single-phase armature reaction is not compensated.

The general effect of load on a generator is to slightly broaden the top of the wave, bending it to the left and making it somewhat unsymmetrical. An inductive load tends to smooth out the harmonics, a condenser load to emphasize them. Curve 34, full load, unity power factor, should be compared with Curve 5 the no-load wave. Curves 35 and 36 show two curves each, one pair at no load, the other at full load. Curves 37-48, inclusive, show the distribution of the flux in the magnetic field in an 860-kv-a., 60-cycle synchronous motor under different conditions, as generator or motor, at 50 per cent and 100 per cent load, unity power factor 0.8 lagging and 0.8 leading, the potential waves in all cases being taken on a special coil. These waves are badly saw-toothed or affected by harmonics. This is due to the fact that they represent the potential of a special coil located in two slots only (see Curve 31). The 100 per cent unity power factor load waves are shown on the same oscillograms as the no-load (Curves 37 and 38). This is simply for convenience of comparison. The spacing between the two curves has no relation to the angular displacement produced by load. Curves 49 and 50 are the potential waves at the terminals of the armature winding itself, of the same machine, for the no-load and 100 per cent load, unity power factor conditions. Curves 51 and 52 show the damping effect on harmonics of a unity power factor load in the case of an induction motor tested as generator, where the definite-wound secondary was used for the direct-current excitation.

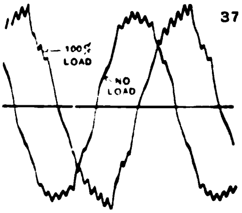
The worst distortion of potential wave is caused by leading current or condenser single-phase load, as a rule. Curves 53 and 54 show the effect of such a load, consisting of underground cable under high-potential test. On the other hand, a poor



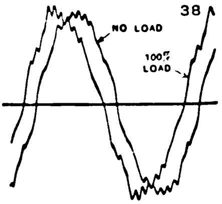
Curve 35.—Potential Waves—No Load.
Upper Curve — Across one phase. Lower Curve —Across two phases. 2100 kv-a., 60 cycles, 1800 rev. per. min. three-phase, 2300 volts.



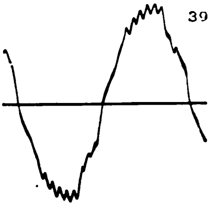
Curve 36.—Potential Waves,— 100 per cent Load — Unity Power Factor.
Upper Curve, Across one phase. Lower Curve, Across two phases. 2100 kv-a., 60 cycles, 1800 rev. per. min., three phase, 2300 volts.



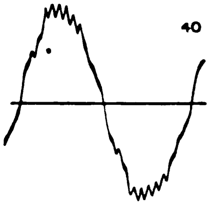
Curve 37.—Potential Waves on Exploring Coil—No-Load, and 100 per cent Load—Unity Power Factor.
860 kv-a., 60 cycles, three-phase 2300 volts.



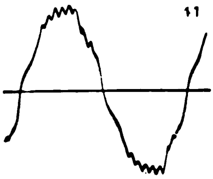
Curve 38.—Potential Waves on Exploring Coil—No Load and 100 per cent Load Unity Power Factor.
860 kv-a., 60 cycles, three-phase 2300 volts, as motor.



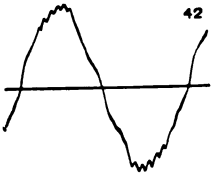
Curve 39.—Potential Wave on Exploring Coil,—50 per cent Load —Unity Power Factor.
860 kv-a., 60 cycles, three-phase, 2300 volts, as generator.



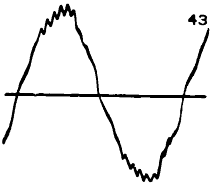
Curve 40.—Potential Wave on Exploring Coil,—50 per cent Load —Unity Power Factor.
860 kv-a., 60 cycles, three-phase, 2300 volts, as motor.



Curve 41.—Potential Wave on Exploring Coil—50 per cent Load — 0.8 Power Factor Lagging.
860 kv-a., 60 cycles, three-phase, 2300 volts, as generator.



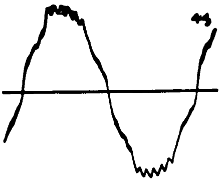
Curve 42.—Potential Wave on Exploring Coil,—50 per cent Load — 0.8 Power Factor Lagging.
860 kv-a., 60 cycles, three-phase, 2300 volts, as motor.



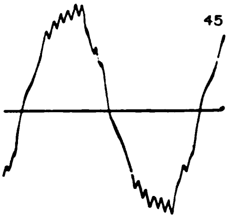
Curve 43.—Potential Wave on Exploring Coil—50 per cent Load — 0.8 Power Factor Leading.
860 kv-a., 60 cycles, three-phase, 2300 volts, as generator.

wave at no load may show a pretty good wave with single-phase condenser load. Curves 55 and 56 illustrate this. The necessity for providing compensating windings in the field to obtain good waves with single-phase leading current is shown in Curves 57-59, inclusive. The compensating windings were not connected in for Curve 58. Curves 60, 61 and 62 are interesting as showing to what extent the single-phase double-frequency flux may be eliminated by a squirrel-cage winding serving as compensating coils.

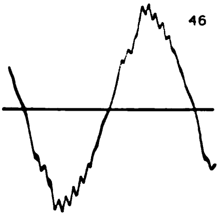
There is considerable deviation from sine wave in many of the synchronous machines in commercial service. Some of them in operation for fifteen or twenty years, have waves as ragged as Curve 55, which was taken on a standard belt-driven, 60-cycle, three-phase generator. Curves 63 and 64 show the no-load potential of two standard 60-cycle, three-phase, 11,000-volt generators of slightly different ratings and speed. Curves 65 and 66 show the waves of two generators, widely different in certain features of design, which are operating in a system of over 100,000 kw. Curve 67 is the wave of an older type of generator operating for several years in parallel with other generators of quite different potential waves in a system of approximately 20,000 kw. The poles of this generator were originally chamfered in a manner similar to that shown in Curve 2. The machine was very noisy when brought to test. The chamfer on poles was changed, with a decided improvement in the matter of noise. Many high-potential synchronous motors with waves showing pronounced harmonics have been operating for years. Curve 68 was taken on a motor where several are in service on a 25-cycle long-distance transmission of approximately 30,000 kw. Approximately 25,000 kw. of motors with waves as in Curve 69 are operating on a 60-cycle system, a long-distance transmission of 35,000 kw Curves 70 and 71 show waves of star-connected generators that operated in parallel for several years without grounded neutral. Curves 72 and 73 show rather unusual examples of star- and delta-connected generators. Several machines of each type in different places have been in service for nearly ten years. Curve 74 is the wave of a 4800-kv-a. generator in a system of about 25,000 kw. Curve 75 belongs to a plant of 24,000 kw. feeding, through step-up transformers, a 60,000-volt transmission. Curve 76 is the wave of a generator operating with others of different design on a system of approximately 10,000 kw. Curve 77 was taken on a generator operating on a



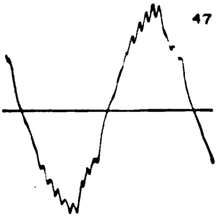
Curve 44.—Potential Wave on Exploring Coil—50 per cent Load—0.8 Power Factor Leading.
860 kv-a., 60 cycles, three-phase, 2300 volts, as motor.



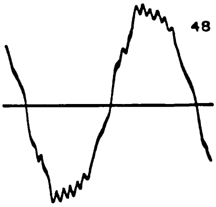
Curve 45.—Potential Wave on Exploring Coil — 100 per cent Load — 0.8 Power Factor Lagging.
860 kv-a., 60 cycles, three-phase, 2300 volts, as generator.



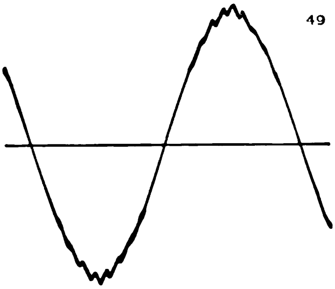
Curve 46.—Potential Wave on Exploring Coil — 100 per cent Load—0.8 Power Factor Lagging.
860 kv-a., 60 cycles, three-phase, 2300 volts, as motor.



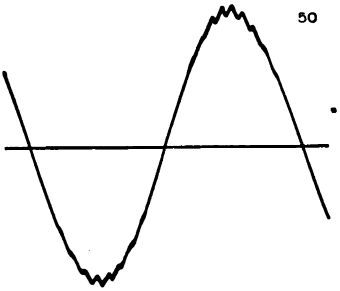
Curve 47.—Potential Wave on Exploring Coil — 100 per cent Load — 0.8 Power Factor Leading.
860 kv-a., 60 cycles, three-phase, 2300 volts, as generator.



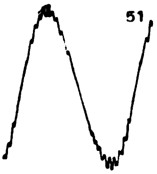
Curve 48.—Potential Wave on Exploring Coil — 100 per cent Load — 0.8 Power Factor Leading.
860 kv-a., 60 cycles, three-phase, 2300 volts, as motor.



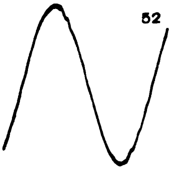
Curve 49.—Potential Wave — No Load.
860 kv-a., 60 cycles, three-phase, 2300 volts.



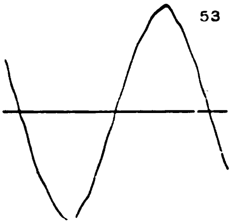
Curve 50.—Potential Wave—100 per cent Load — Unity Power Factor.
Motor generator combination of a pair of machines. 860 kv-a., 60 cycles, three-phase, 2300 volts.



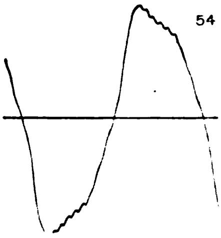
Curve 51.—Potential Wave—No Load.
9 kv-a., 60 cycle, three phase, induction motor, as generator, with d-c. excitation from all three phases of secondary.



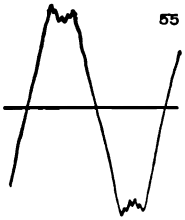
Curve 52.—Potential Wave — 100 per cent Load.
9 kv-a., 60 cycle, three-phase, induction motor, as generator, with d-c excitation from all three phases of secondary.



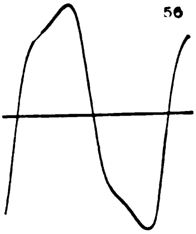
Curve 53.—Potential Wave — No Load.
90 kv-a., 25 cycle, 500 volt, three-phase generator.



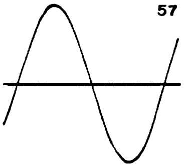
Curve 54.—Potential Wave, Single Phase, Condenser Load.
90 kv-a., 25 cycle, 500 volt, three-phase, generator.



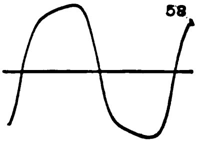
Curve 55.—Potential Wave — No Load.
36 kv-a., 60 cycle, 1150 volt, three-phase, generator.



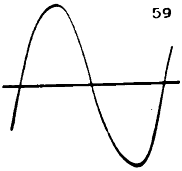
Curve 56.—Potential Wave — Single Phase—Condenser Load.
36-kv-a., 60-cycle, 1150-volt, three-phase, generator.



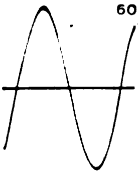
Curve 57.—Potential Wave—No Load.
50 kv-a., 60 cycle, cylinderical rotor, single-phase, alternator.



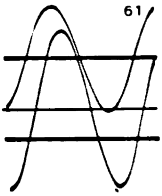
Curve 58.—Potential Wave — Condenser Load.
50 kv-a., 60 cycle, cylindrical rotor, single-phase, alternator-compensating coils in field inactive



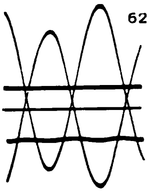
CURVE 59.—POTENTIAL WAVE — CONDENSER LOAD.
50 kv-a., 60 cycle, cylindrical rotor, single-phase, alternator, compensating coils in field active.



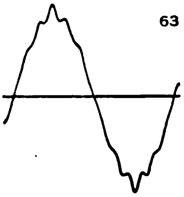
CURVE 60.—POTENTIAL WAVE — NO LOAD.
625 kv-a., 80 cycle, 2100 volt, single-phase generator.



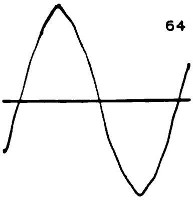
CURVE 61.—OSCILLOGRAMS, UNITY POWER FACTOR, THREE-PHASE LOAD.
Upper Curve, Armature current. Middle Curve, Armature voltage. Lower Curve, Field current. (Upper curve, separate exposure) 625 kv-a., 80 cycle, 2100 volt, single-phase generator.



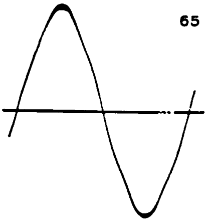
CURVE 62. — OSCILLOGRAMS, 100 PER CENT LOAD, UNITY POWER FACTOR.
Upper Curve, Armature Current. Middle Curve, Armature voltage. Lower Curve, Field current.



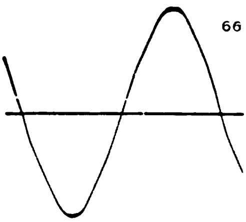
CURVE 63.—POTENTIAL WAVE — NO LOAD.
600 kv-a., 60 cycle, 600 rev. per. min., three-phase, 11000 volts.



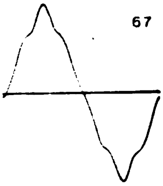
CURVE 64.—POTENTIAL WAVE — NO LOAD.
650 kv-a., 60 cycle, 514 rev. per. min., three-phase, 11000 volts.



CURVE 65.—POTENTIAL WAVE—NO LOAD.
4500 kv-a., 25 cycle, 250 rev. per. min., two-phase, 2200 volts, external field generator.

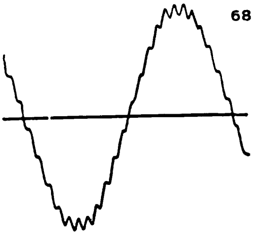


CURVE 66.—POTENTIAL WAVE—NO LOAD.
4500 kv-a., 25 cycle, 250 rev. per min., two-phase, 2200 volt, internal field generator.



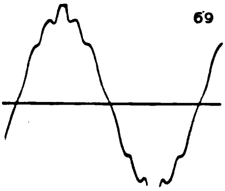
67

Curve 67.—Potential Wave — No Load. 2400 kv-a., 60 cycle, 106 rev. per min., two-phase 6000 volts.



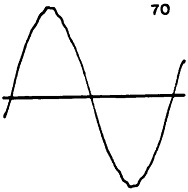
68

Curve 68.—Potential Wave — No Load. 2100 kw., 25 cycle. three-phase, 13200 volt synchronous motor.



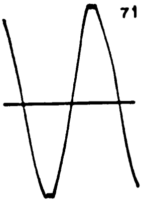
69

Curve 69.—Potential Wave—No Load. 2100 kw., 60 cycle, three-phase. 11000 volt synchronous motor.



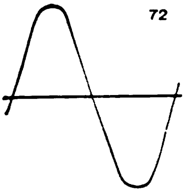
70

Curve 70.—Potential Wave — No Load. 7000 kv-a., 60 cycle, three-phase, 6900 volt generator.



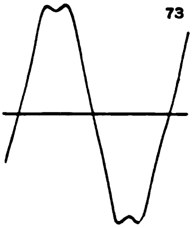
71

Curve 71.—Potential Wave — No Load. 7000 kv-a., 60 cycle, three-phase, 6900 volt generator.



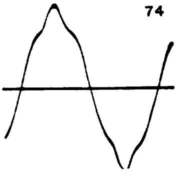
72

Curve 72.—Potential Wave — No Load. 2800 kv-a., 25 cycle, three-phase, 13200 volt generator, star connected.



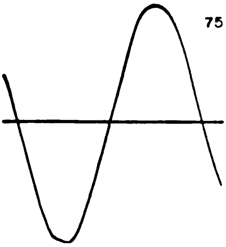
73

Curve 73.—Potential Wave — No Load. 4200 kv-a., 60 cycle, three-phase, 2300 volt generator; delta connected.

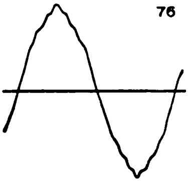


74

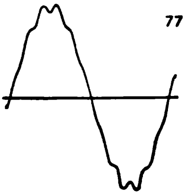
Curve 74.—Potential Wave — No Load. 4800 kv-a., 60 cycle, three-phase, 13200 volt, generator.



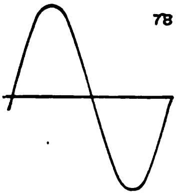
Curve 75.—Potential Wave — No Load. 3000 kv-a., 60 cycle, three-phase, 2300 volt generator.



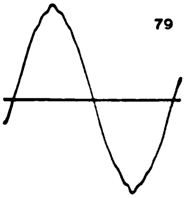
Curve 76.—Potential Wave — No Load. 2400 kv-a., 25 cycle, three-phase, 5000 volt generator.



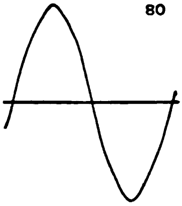
Curve 77.—Potential Wave —No Load. 4200 kv-a., 60 cycle, three-phase, 11000 volts.



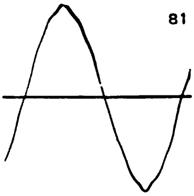
Curve 78.—Potential Wave — No Load. 3600 kv-a., 40 cycles, three-phase, 4400 volt generator.



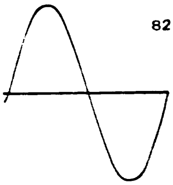
Curve 79.—Potential Wave — No Load. 12000 kv-a., 60 cycle, three-phase, 11000 volt generator.



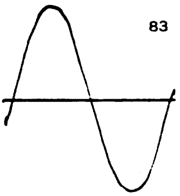
Curve 80.—Potential Wave — No Load. 3000 kv-a., 60 cycles, 360 rev. per min., three-phase, 6600 volt, generator



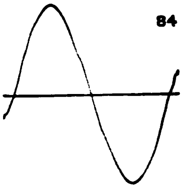
Curve 81.—Potential Wave — No Load. 3000 kv-a., 60 cycle, 164 rev. per min., three-phase, 6900 volts.



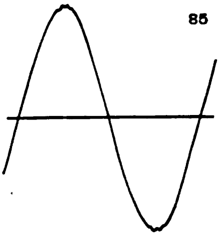
Curve 82.—Potential Wave — No Load. 3000 kv-a., 60 cycle. 133 rev. per min., three-phase, 2300 volts.



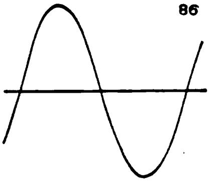
CURVE 83.—POTENTIAL WAVE — NO LOAD. 3600 kv-a., 60 cycles, three-phase, 4000 volts.



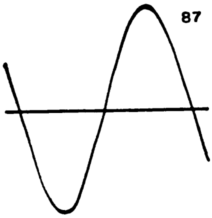
CURVE 84.—POTENTIAL WAVE — NO LOAD. 9000 kv-a., 25 cycle, 375 rev. per min., three-phase, 6600 volt generator.



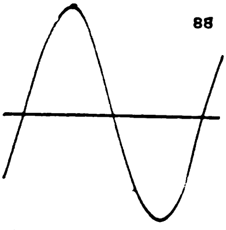
CURVE 85.—POTENTIAL WAVE — NO LOAD. 9000 kv-a., 25 cycle, 750 rev. per min., three-phase, 13200 volts.



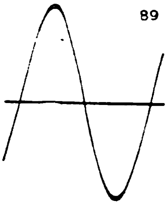
CURVE 86.—POTENTIAL WAVE — NO LOAD. 5555 kv-a., 25 cycle, 1500 rev. per min., three-phase, 13200 volts.



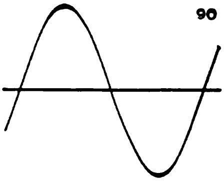
CURVE 87.—POTENTIAL WAVE — NO LOAD. 14,000 kv-a., 60 cycle, 720 rev. per min., three-phase, 4600 volts.



CURVE 88.—POTENTIAL WAVE — NO LOAD. 2500 kv-a., 25 cycle, 1500 rev. per min., three-phase, 2300 volts.



CURVE 89.—POTENTIAL WAVE — NO LOAD. 9375 kv-a., 60 cycle, 1800 rev. per min., three-phase, 5000 volts.



CURVE 90.—POTENTIAL WAVE — NO LOAD. 9375 kv-a., 30 cycle, 1800 rev. per min., three-phase, 7200 volts.

system extending over a vast area with several generating plants. Curve 78 is the wave of a generator in one plant of a 30,000-volt transmission of 15,000 kw. Curve 79 is the wave of a generator in a 50,000 kw. plant stepping up to 100,000 volts. Curves 80, 81 and 82 show waves of 3000-kv-a. 60-cycle generators of three different speeds. Curve 83 shows the wave of a generator of the same design, in most of its parts, as that of Curve 81. Curve 84 is the wave of generators in a large hydroelectric plant.

In connection with cylindrical rotor generators with uniform air gap the distributed field winding serves the same purpose as the shaping of pole in shading the flux in air gap. This class of machines has the advantage of a greater distribution of the armature winding. Curves 85-90, inclusive, are examples of steam-turbine generators of comparatively recent designs. Curve 85 is on a generator at 750 rev. per min. and is not quite so good as Curve 86 on a 1500-rev. per min. generator of the same potential, 13,200 volts, and same periodicity, 25 cycles. Although the latter is of smaller capacity, it has the advantage, in the matter of potential wave, of a greater distribution of windings in both armature and field.

The ratings used in this paper are on the single or continuous rating basis. Consequently, the ratings on the name plates of the generators do not in all cases agree with those here used.

METHOD OF DETERMINING TEMPERATURE OF ALTERNATING CURRENT GENERATORS AND MOTORS AND ROOM TEMPERATURE

BY

HENRY G. REIST and T. S. EDEN

Presented under the auspices of the

Standards Committee

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METHOD OF DETERMINING TEMPERATURE OF A-C. GENERATORS AND MOTORS, AND ROOM TEMPERATURE

BY HENRY G. REIST AND T. S. EDEN

Abstract of Paper

In this paper, attention is called to various methods of determining temperature of apparatus, recommendations being made for the use of a definite covering for thermometer bulbs, based on the results of experiment.

Measurement of temperature by resistance is confined to the rotor windings of machines on which thermometers cannot be applied; the inaccuracy of this determination for stators is pointed out.

Temperature measurement by special coils inserted in the windings is recommended for machines of fairly high capacity, wound for 6600 volts and above.

For room temperature determination in general, a metal cylinder covering for thermometer bulbs is recommended.

Room temperature determination is shown to be of primary importance and a fair room temperature must be arrived at, in different ways, depending on the method of ventilation used.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26–28, 1913

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(*Subject to final revision for the Transactions.*)

METHOD OF DETERMINING TEMPERATURE OF ALTERNATING CURRENT GENERATORS AND MOTORS AND ROOM TEMPERATURE

BY HENRY G. REIST AND T. S. EDEN

Correct determination of the temperature of apparatus is of great importance to the designing engineer. Of even greater importance, is the determination of a fair room temperature, since all temperature guarantees are made on the basis of rise above room.

The determination of the temperature of apparatus may be made by thermometer, by resistance measurement or in special cases by the use of temperature measuring coils.

THERMOMETER

In the use of thermometers, it is obviously necessary to select the means of applying and covering the bulbs which will give on the one hand the maximum temperature attained and on the other, will not increase temperature of part where the thermometer is applied. Several coverings are available such as cotton or woolen waste, felt, putty etc. To determine which of these coverings is the most suitable, the following experiment was recently made.

A copper plate was fitted over the top of a vessel containing water, so that it could be uniformly heated, and the temperature changed as desired. Bulbs covered with different materials were applied to the copper plate and temperatures read over a range from 86 deg. cent. to 32 deg. cent. The following table gives the results.

The temperatures as read across the table herewith, were taken at the same time, and after they had become constant

Covering	Putty 1 in. dia.	Fibre tube 1¼ in. dia. Top filled with waste	Felt 2 in square	Woolen waste 2 in. dia.	Cotton waste 2 in. dia.	Uncovered between preceding	
Temp. deg. cent.	86	78	79	81	82	68	69
	71.5	66	66	68	68	59	59
	62.5	57.5	57.5	60	60	50.5	51.5
	51.5	47.5	47.5	49	49	44.5	44.5
	42	40.5	40.5	40.5	41	38.5	38
	37	35.5	35.5	36	36	34.5	34.5
	32	31.5	31.5	31.5	32	30.5	30.5

These thermometers were then carefully calibrated over a temperature range from 89 to 26 deg. cent and found to agree within one deg. at the higher temperatures and one-half deg. at the lower temperatures. The table shows that the bulb covered with putty gives the highest reading in each case.

It is therefore recommended that putty covering be used as the standard, since it not only gives the highest reading but is convenient to handle and can be applied in a compact form, not covering an unnecessarily large area, which would impede natural radiation.

RESISTANCE MEASUREMENT

Measurements of resistance both cold and hot may be accurately taken but in practice it is found that the temperature *cold* is uncertain.

This is due to a possible or perhaps even a probable difference of average temperature of the winding of which the resistance is to be measured from that of the measured temperature of the air.

A resistance measurement on an armature winding taken at a temperature below 25 deg. cent. and again at a temperature above 25 deg. cent. when reduced to resistance at 25 deg. cent. will seldom check within 5 per cent. Consequently manufacturers must build with larger margins when required to guarantee temperatures by resistance.

The temperature of windings so determined, is not a gage of the highest temperature attained, but is an average temperature. The temperature of the end windings on an armature will usually be lower than that of the portion of the winding imbedded in the slot; similarly on revolving field windings, the temperature indicated by the *IR* drop, will frequently be found lower than that shown by thermometers applied to parts of the coils, for example adjacent to mechanical supports between coils.

This method of obtaining temperature rise on alternating current generators and synchronous motors, should be limited to the revolving field windings of those machines which are so enclosed that thermometer application is impossible.

Temperature Measuring Coils

In apparatus such as steam turbine-driven and large high-speed waterwheel-driven generators where the stator windings are inaccessible for thermometers, it is possible to determine the temperature of these parts by using small coils of fine wire, non-inductively wound which may be placed next to the insulated coil in the slot portion or outside, as desired. Accurate measurements of resistance of these coils by voltage drop may be taken and the highest temperatures attained, may be known.

These coils should be calibrated at a known temperature before being put into a machine.

This method may be applied to any machine and will bring to light faulty design. Insulating fabrics, such as oiled linen, varnished cambric etc., are apt to deteriorate more rapidly than desirable between temperatures of 90 and 100 deg. cent. and consequently apparatus so built should not be permitted to run at these temperatures. Other insulating materials are in use and also in process of development, which will permit of operation at higher temperatures than these. This method is recommended for the investigation of temperatures in factory tests but customers should not require it on more than one of several duplicate machines, unless they are willing to stand the attendant expense, since thermometer readings would be sufficient to show that two or more machines were alike.

For machines with small slots, this method of determination should not be necessary.

Its field of application should probably be in apparatus of 6600 volts and over, and on machines of outputs above 2000 kw.

A few examples are given to show how the temperature *rises* measured differ by thermometer, resistance, and temperature coil on one and the same heat run.

The value of this table is more as a comparison of the different methods of measuring temperature, than an indication of the maximum temperatures in a machine, since the tests were not made under full load conditions, but under such artificial loads as could be obtained at the time the machines were in test.

Size of generator	Voltage	Thermometer	Resistance	Temperature Coil
15000 kw.	9000	27	40	44
8750 kw.	6900	22	26	39
6000 kw.	6600	29	35	39
5000 kw.	4000	19	33	44
4000 kw.	4000	15	27	30
3750 kw.	6600	15	30	33
3750 kw.	6600	19	30	33

This substantiates the fact that internal temperatures are considerably higher than outside temperatures in a machine.

It is hard to form a conception of the internal temperature of a coil by external thermometer reading, since with a given loss per unit of area of surface of the coil, the external temperature is very largely dependent on the rate of flow of the cooling air over the surface, whereas the difference of temperature between the inside and outside is a factor of the rate of transmission per unit cross section of the material used in insulating and of its thickness.

In the rotors of turbo-driven generators, on account of the construction necessary, temperatures greater than in the stators will result requiring the use of insulations which will stand such temperatures.

On this part of a machine there appears to be no difficulty in making an insulation safe for these higher temperatures, due to the low potential employed for excitation.

The determination of these temperatures should be by resistance, calculated from the *I R* drop. To apply temperature measuring coils would be extremely difficult and expensive, involving auxiliary collector rings for measuring the resistance and introducing inaccuracies of measurement as compared with coils in a stator.

Room Temperature

Commercial testing must necessarily be conducted in rooms where the temperature will vary and where apparatus and room thermometers will be subjected to air currents caused by opening of doors or windows.

Machines of small volume will respond quickly to changes in temperature of the surrounding air, whereas the temperature change in large machines, will lag appreciably behind the change in room temperature.

It is therefore necessary to find some means of lagging the bulbs of thermometers used for determination of room temperature, so that the changes will follow approximately the same curve as the apparatus. For this purpose, a small steel cylinder with a hole in the center, filled with oil in which the thermometer is placed, has been used by some manufacturers.

In order to determine their heat capacity a series of these cylinders was made up 3 in. (7.6 cm.), 2 in. (5.1 cm.), 1⅜ in. (3.5 cm.) 1 in. (2.54 cm.) and ¾ in. (1.9 cm.) in diameter all 3 in. (7.6 cm.) high, all provided with a ⅜-in. (9.5-cm.) diameter hole, 1½ in. (3.8 cm.) deep for the thermometer. They were heated up to approximately the maximum temperature reached by a machine at the end of a heat run, and temperature recorded at frequent intervals, also of the machine running idle. These readings are shown in Fig. 1.

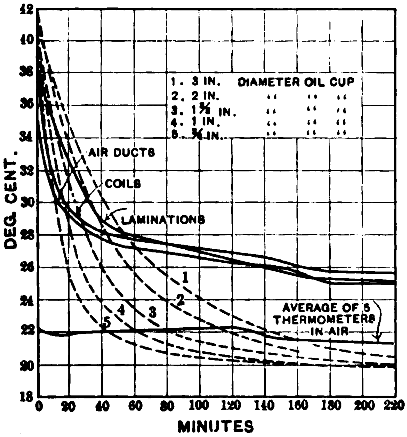

FIG. 1—COOLING CURVE OF 860 KV-A., 2300-VOLT, 720-REV. PER. MIN. 60-CYCLE ALTERNATOR, AND OIL CUPS.

It will be noted that the cooling curve of the 3-in. (7.6- cm.) oil cup as these cylinders may be called, follows the laminations and the ¾-in. (1.9- cm.) oil cup follows the coils over the higher temperatures recorded, or those temperatures which the machine parts attained under heat run.

Constant temperature of the machine parts is reached at a temperature above that of the room, due to warming up of the air passing through the machine, running at full speed.

It would therefore seem reasonable in determining the room temperature to use an oil cup 2 in. (5.1 cm.) in diameter which will follow the average temperatures of the different parts of the machine.

Similarly on a 3750-kv-a. unit, Fig. 2 shows that the cooling curve of the 2-in. (5.1- cm.) oil cup follows the temperature changes of the laminations very closely.

These oil cups, together with air suspended thermometers were then used in connection with a machine in test, which had reached constant temperatures. Doors were opened for an hour so as to reduce room temperature and temperatures recorded as shown in Fig. 3.

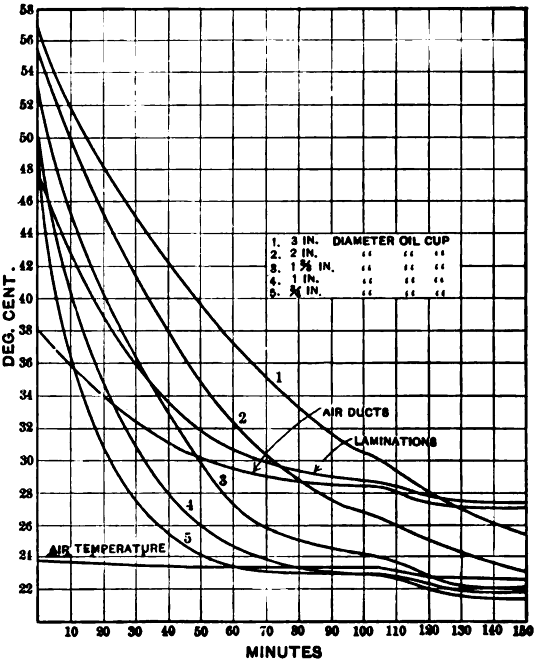

FIG. 2—COOLING CURVE OF 3750-KW. 6600-VOLT, 500-REV. PER. MIN. 50-CYCLE ALTERNATOR, AND OIL CUPS.

The following table shows temperature rises above the air suspended thermometers and above the 2-in. (5.1-cm.) diameter oil cup.

This shows that the temperature rises above the oil cup are fairly uniform and those above the air thermometer vary a great deal.

	Rise over air thermometer	Rise over oil thermometer
Doors opened	28.6	30.2
10 minutes later	33.2	31
10 " "	31.7	31.1
10 " "	29.2	30
10 " "	28.4	29.7 etc.

From these and other observations of a similar nature which have been made, it is recommended that an oil cup of this sort be used for determining room temperatures, both on account of its convenience and accuracy.

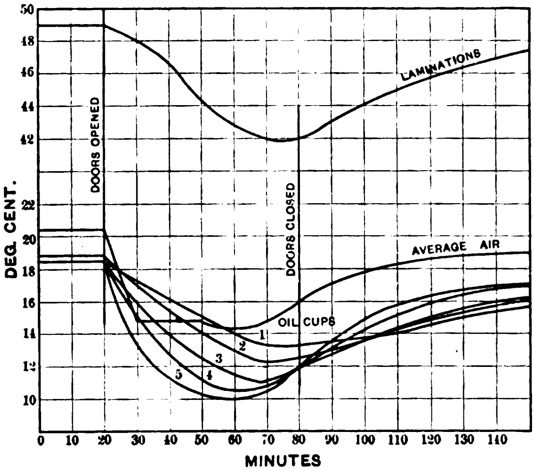

FIG. 3—COOLING CURVE OF 860-KV-A., 2300-VOLT, 720-REV. PER MIN. 60-CYCLE ALTERNATOR, AND OIL CUPS.

It is possible that for stationary apparatus, such as transformers, a satisfactory solution may be arrived at by taking the temperature of an idle machine, the cooling medium being air, water, oil, etc. However for rotating apparatus, we believe the above method will give reasonably accurate results.

Several different methods of ventilation are used in alternating-current apparatus and the " room temperature " cannot be arrived at in the same way for all cases.

The majority of machines built, take their cooling air from the room they are in and deliver it to the same room. For these, " room temperatures " should be determined in some such manner as given above.

Frequently, with horizontal machines ventilated in this manner, a large part will be below the floor line of a station, in a pit. Unless such a pit is properly ventilated, a portion of the stator will show temperature rises which are dependent on the temperature of the air in the pit, and the rises of such a portion should be based on the pit temperature. It might be noted that the portion so affected will come below the floor line on the one side and above on the other depending on the direction of rotation. The temperature of the rotor should be referred to an average of the pit and room temperatures, the value of each being decided on the portion of the machine in pit.

For vertical types ventilated in this manner, we would recommend placing the room temperature thermometers at the level of the center line through the magnetic material, since the temperature so obtained would be practically an average of that above and below a machine in test.

However, if a machine is totally enclosed, taking its air from and delivering it, outside the room, the temperature on which the rise is based should be that of the air entering, applying a correction factor for the difference between the temperature of the ingoing air and that of the air surrounding the machine. A fair value to give to each for this type of machine might be four (4) for ingoing air, to one (1) for surrounding, air: *e.g.* air entering at 15 deg. cent. room at 30 deg. cent.; basis for temperature rise, 18 deg. cent.

Where the frame of a machine is open, so that the air delivered from outside, passes through into the room, the correction factor might be applied by giving a value of two (2) to the ingoing air and one (1) to the surrounding air *e.g.*, air entering at 15 deg. cent. room at 30 deg. cent. basis for room temperature 20 deg. cent.

It would be very difficult to make an exact determination of these correction factors. The above are given as suggestions, which we believe would be fair. Doubtless, many cases will arise which can only be settled on their individual merits.

We appreciate that the tests are not sufficient to base conclusions on and that probably more extended tests will be advisable.

At best however, the size of oil cup will have to be a compromise because it will not be practicable to change the size of cup for different machines or to use different cups for comparison with different parts of a machine.

A PROPOSED WAVE SHAPE STANDARD

BY

CASSIUS M. DAVIS

Presented under the auspices of the

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A PROPOSED WAVE SHAPE STANDARD

BY CASSIUS M. DAVIS

Abstract of Paper

The present wave-shape standard has several objections, principal among which are the use of the oscillograph, the lengthy calculations necessary and the discrimination in favor of higher harmonics.

The proposed standard makes use of the change of effective reactance of a condenser with change of wave shape. The important advantages are: the wave shape distortion can be determined very quickly; the distortion depends in a very definite way upon the harmonics present, both as to order and magnitude; the apparatus is very simple and the test easily manipulated. The disadvantage is that it does not show which harmonics are present.

The ratio of the condenser reactance on a sine wave to the condenser reactance on the distorted wave is called the distortion ratio. It is conveniently determined by impressing the wave shape to be measured, first on a condenser with a large inductive reactance in series, and then on the condenser alone. The current and voltage at the condenser terminals in each case determine the reactance.

The measurement of the distortion ratio on generating apparatus should be made at full voltage no-load, since the wave shape at load is indefinite.

Several oscillograms show wave shapes recently observed and accompany ing them are the distortion ratios, the deviations and the analyses.

The paper concludes with proposed substitutes for the present A. I. E. E. Standardization Rules.

The derivation of the theoretical formula for distortion ratio is given in the appendix. Tables are also given to serve as a guide in determining permissible distortion.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26–28, 1913.

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(*Subject to final revision for the Transactions.*)

A PROPOSED WAVE SHAPE STANDARD

BY CASSIUS M. DAVIS

The present wave shape standard states that " a maximum deviation of the wave from sinusoidal shape not exceeding 10 per cent is permissible," where the deviation has to be determined by measurements from an oscillogram or a wave form determined from a wave meter.

The objections to this standard may be summarized thus:

1. The use of an oscillograph or a wave meter is required; often neither is available.

2. It is necessary to measure a large number of ordinates on the wave form, from which the equivalent sine wave is calculated.

3. The position of minimum difference between the distorted wave and its sine equivalent must be determined either by repeated trial calculations, or by plotting the equivalent sine wave on a separate sheet which can be applied to the distorted wave and the minimum difference measured. As a rule, in practical work, little attention is paid to the position of minimum difference.

4. The results obtained discriminate in favor of the higher harmonics. For instance, consider a voltage wave that consists of a fundamental and 17th harmonic of 10 per cent amplitude. The equivalent sine wave is almost identical with the fundamental and the deviation is approximately 10 per cent. If this wave be impressed upon a circuit containing dielectric capacity, as in the case of a transmission line, the capacity current does not consist of the fundamental and 10 per cent 17th harmonic, but has the fundamental and 170 per cent 17th harmonic. Again, if a voltage wave consists of a fundamental and 3rd harmonic of 10 per cent, while the equivalent sine wave is still nearly

identical with the fundamental and the deviation is about 10 per cent, yet its capacity current into a condenser consists of 100 per cent fundamental and a 30 per cent 3rd harmonic. In the first instance the effective value of the current is 197 per cent based on the fundamental of current, while in the second case the effective value is about 105 per cent on the same basis, and in both cases the deviation of the voltage wave is the same. If these same voltage waves be impressed upon an inductive circuit the opposite effect is produced and the currents have a larger effective value when lower harmonics are present. Now, however, the effective values tend to approach 100 per cent and the distortion does not become so important.

To overcome the above objections a revision of the rule governing permissible wave shape distortion is suggested which shall take into account the various harmonics of a wave in proportion to the maximum effect which they respectively can produce.

The objection noted under (4), relative to the increase of capacity current taken by a condenser, serves as the basis for one way of determining wave shape distortion. The capacity current of a condenser is proportional to the frequency and the applied e.m.f., thus when a distorted voltage wave, consisting of a fundamental and its harmonics, is impressed upon a condenser the effective current is greater than for a sine wave of the same effective value, and furthermore, it is greater in a definite proportion the greater the amplitude and the frequency of the harmonics. In other words, the apparent reactance of a condenser is less on a distorted wave than it is on a sine wave. Thus, we may measure wave shape distortion by the ratio of the reactance of a given condenser on a sine wave to the reactance of the same condenser on the distorted wave, and the permissible wave shape distortion may be defined by assigning a definite value to the ratio. This method of determining the distortion takes into account all harmonics in exact proportion to their amplitudes and frequencies and gives a measure of the maximum effect which a distorted wave can have on a circuit.

Since the harmonics which are liable to occur in electrical apparatus are of smaller amplitude the higher their order, it is possible to say that their probable amplitude is expressed as a/n per cent of the fundamental, where n is the order of the harmonic and a is a constant. If we assign a value to the distortion ratio mentioned above, and assume there are a given number of harmonics present, a has a definite value. It is only necessary then to determine the distortion ratio which is permissible in commercial electrical apparatus to fix a fair value for a. This has been done in a preliminary way and the average of tests on 22 commercial alternators gives a distortion ratio of 1.135 which, assuming there are five odd harmonics present besides the fundamental, gives a a value from 0.165 to 0.168. The constant a has a series of values depending upon which five harmonics are present. The accompanying Table I shows the values which a may have when there are the first m odd harmonics present, and Table II gives the values of a when there are the last m odd harmonics present, assuming the 25th as the highest probable harmonic present in commercial waves.

TABLE I.

Values of a for the first m consecutive odd harmonics.

δ	m						
	1	2	3	4	5	6	7
1.05	0.342	0.236	0.191	0.163	0.146	0.133	0.123
1.10	0.493	0.340	0.274	0.236	0.210	0.191	0.176
1.15	0.615	0.423	0.341	0.293	0.261	0.237	0.219
1.20	0.724	0.497	0.400	0.343	0.305	0.278	0.255

TABLE II.

Values of a for the last m consecutive odd harmonics, assuming the 25th to be the highest probable harmonic in commercial generating apparatus.

δ	m						
	1	2	3	4	5	6	7
1.05	0.320	0.227	0.185	0.160	0.143	0.131	0.121
1.10	0.459	0.324	0.265	0.229	0.205	0.187	0.174
1.15	0.568	0.402	0.328	0.284	0.254	0.232	0.216
1.20	0.664	0.470	0.383	0.332	0.297	0.271	0.251

NOTE: Attention is called to the fact that for a given number of harmonics the values of a lie within relatively narrow limits as may be noticed by comparing Tables I and II

Where the distortion ratio is to be determined on alternators, and other apparatus subject to load, it should be measured at no load. It is recognized that any load may change the wave shape; but since its character may vary widely, no definite conditions can be specified under which a load distortion ratio might be taken. With a load of synchronous machines, no specification of the generator wave shape can be made, as it depends more or less on the wave shape of the synchronous motor or converter, and in such a case the wave shapes of the generator as well as the synchronous motor or converter would have to be considered; the wave shape of the circuit being a combination of the two.

On non-inductive load the wave shape is generally rather immaterial; on inductive load it is more sinusoidal, due to the suppression of higher harmonics by the reactance, and an exaggeration of wave shape distortion over that observed at no-load can be expected only from a load with leading current, as a transmission line or cable system. As the proposed method of wave shape specification by the current flowing in a condenser exaggerates the distortion of the no-load wave in the same manner as a leading current load does, the proposed method specifies the no-load wave shape in such a manner as to give weight to the probable distortion which may be expected with a leading current load, and thus appears to make wave shape tests under load unnecessary. It is difficult to load large machines non-inductively, impractical to load them inductively and almost impossible to give them a condenser load. Therefore the proposed method of wave shape specification, which in the no-load wave gives the maximum distortion probable under any kind of load, appears especially suitable.

TABLE III.

Amplitudes of harmonics for various values of a. Values are in per cent.

Harmonic	a			
	0.20	0.25	0.30	0.35
3rd	6.67	8.33	10.00	11.67
5th	4.00	5.00	6.00	7.00
7th	2.86	3.57	4.29	5.00
9th	2.22	2.78	3.34	3.89
11th	1.82	2.27	2.73	3.18
13th	1.54	1.92	2.31	2.69
15th	1.33	1.67	2.00	2.34
17th	1.18	1.47	1.76	2.06
19th	1.05	1.32	1.58	1.84
21st	0.95	1.19	1.43	1.67
23rd	0.87	1.09	1.30	1.52
25th	0.80	1.00	1.20	1.40

The apparatus necessary to measure voltage wave shape distortion is very simple. It may consist of a portable set made up of a condenser, a reactive coil and a transformer with various taps, and connected as indicated in Fig. 1. The voltmeter and ammeter readings determine the condenser reactance. The reading is first taken when the double pole double throw switch is in position 1, and the reactive coil is in series with the condenser. This gives the sine wave reading, since the reactive coil damps out the harmonics and gives practically a sine wave of impressed e.m. f. on the condenser. Then the reactive coil is cut out by throwing the switch to position 2, and the condenser reactance measured with the distorted wave impressed directly upon the condenser. The ratio of the first reactance to the second gives the wave shape distortion ratio. The transformer is necessary here in order to give approximately the same voltage across the condenser for either position of the switch.

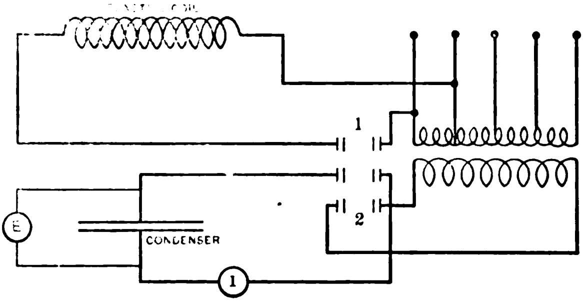


FIG. 1

By a convenient arrangement of switches and transformer taps a set may be made which could be readily applied to a circuit of any frequency and voltage. The current taken by the set should be less than 5 per cent of the full load current of the apparatus under test in order not to distort further the wave which is being measured. The reactive coil should be large enough to damp the lowest harmonic, the third, to at least 2.2 per cent of its fundamental, for if it is above this value the distortion ratio would become greater than 1.002 which would introduce an appreciable error.

Of course this method of determining wave shape distortion does not show which harmonics are present, and where this information is necessary the wave form must be found by the oscillograph or the wave-meter, and analyzed.

The accompanying Figs. 2 to 4 show a few of the more distorted waves which have been measured recently by both the present A.I.E.E. method and that proposed in this paper.

In each case the wave has been carefully analyzed and the theoretical and measured distortion ratios compared. Fig. 5 shows a wave which has an exceptionally large distortion ratio.

Using the above as a basis the following are suggested as substitutes for the present A.I.E.E. Standardization Rules on Wave Shape Distortion:

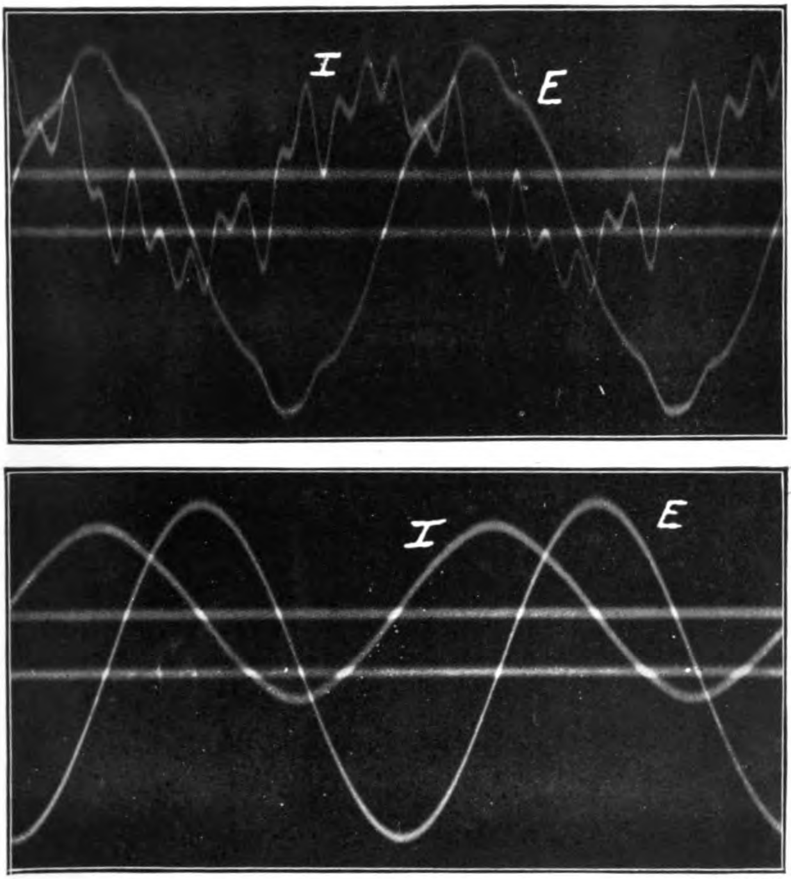
TABLE IV

List of alternators upon which the distortion ratio has been measured. Values taken at full voltage and no load. All these machines have a frequency of from 40 to 62½ cycles, and the output is given on a single rating basis.

No. of phases	Kv-a. output	No. of poles	Voltage	Ratio
3	1500	24	2300	1.031
3	900	36	2300	1.014
3	500	48	2300	1.135
3	720	60	600	1.010
3	1600	14	2300	1.047
3	1200	48	600	1.017
3	1440	48	2300	1.068
3	700	10	2200	1.030
2	1440	24	2300	1.017
3	390	48	2200	1.111
2	375	12	2300	1.017
3	1350	14	11000	2.360
3	375	28	2300	1.002
3	4500	12	6600	1.090
3	240	18	600	1.036
3	288	10	2300	1.018
3	450	48	600	1.034
3	300	14	2300	1.022
3	675	32	600	1.001
3	300	60	2300	1.673
3	1200	24	2300	1.238
3	1140	30	2200	1.006

The wave shape distortion ratio at no-load should not exceed 1.15, except when otherwise specified.

The distortion ratio is determined by impressing the wave form on a suitable condenser, measuring the reactance offered by such condenser to the flow of current and comparing this reactance to the true reactance of the same condenser as measured with a sine wave of current. The latter may be determined by measuring the condenser reactance on any wave shape with an inductive reactance in series, having less than 10 per cent



[C. M. DAVIS]

FIG. 2.—WAVE SHAPE OF THREE-PHASE, 500 KV-A., 48-POLE, 2300-VOLT GENERATOR.

Distortion ratio = 1.135. Deviation (by present A. I. E. E. rule) 8.7 per cent.

$$E = 3248 \cos(\theta - 87°) + 172 \cos(5\theta - 87°) + 80 \cos(7\theta - 67°) + 34 \cos(11\theta + 70°) + 39 \cos(13\theta - 43°)$$

$$I = 1.32 \cos(\theta - 83°) + 0.41 \cos(5\theta - 65°) + 0.27 \cos(7\theta - 62°) + 0.11 \cos(11\theta - 27°) + 0.36 \cos(13\theta + 30°)$$

The lower curves show how the same generator voltage wave is smoothed out to nearly sinusoidal shape by the reactive coil in series.

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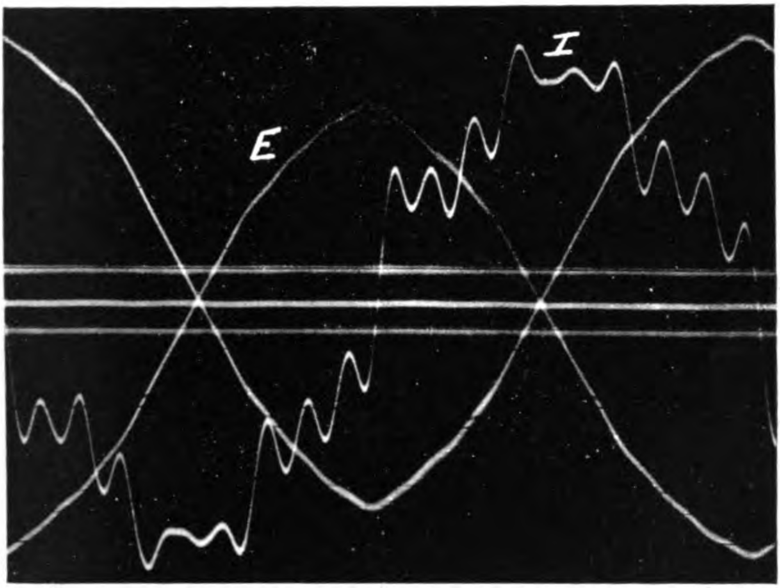

[C. M. DAVIS]

FIG. 3.—WAVE SHAPE OF THREE-PHASE, 45-KV-A., SIX-POLE, 120-VOLT GENERATOR.

Distortion ratio = 1.020. Deviation 5 per cent

$$E = 166.7 \cos(\theta - 90°) + 2.95 \cos(5 \ + 84°) + 2.04 \cos(7\theta + 85°)$$
$$+ 0.80 \cos(11\theta - 67°) + 0.66 \cos(17\theta + 77°) + 0.49 \cos(19\theta - 69°)$$

$$I = 5.43 \cos(\theta + 87°) + 0.55 \cos(5\theta + 77°) + 0.50 \cos(7\theta + 80°)$$
$$+ 0.37 \cos(11\theta - 68°) + 0.57 \cos(17\theta - 68°) + 0.33 \cos(19\theta - 79°)$$

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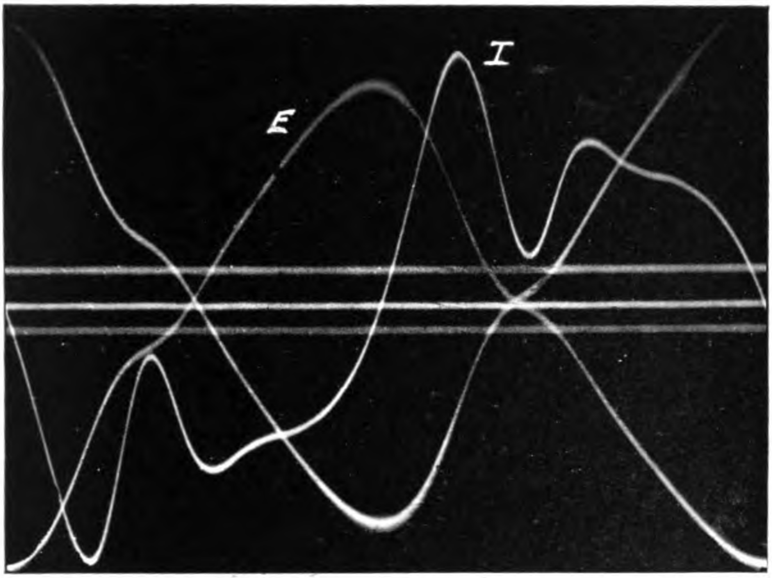


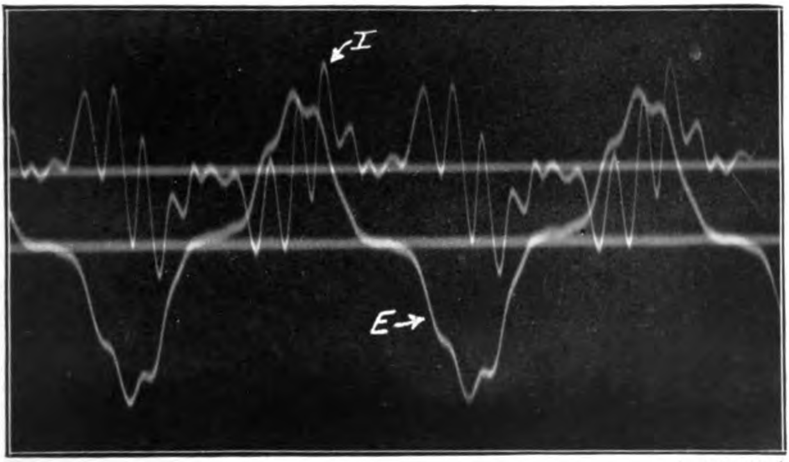
[C. M. DAVIS]

FIG. 4.—WAVE SHAPE OF THREE-PHASE, 10-KV-A., SIX-POLE, 120-VOLT GENERATOR.

Distortion ratio 1.140 Deviation 15.7 per cent

$$E = 166 \cos (\theta - 88^\circ) + 22 \cos (3\theta + 87^\circ) + 8.3 \cos (5\theta - 4^\circ) + 2 \cos (7\theta + 31^\circ) + 1.5 \cos (9\theta - 22^\circ)$$

$$I = 5.41 \cos (\theta + 82^\circ) + 2.04 \cos (3\theta + 85^\circ) + 1.45 \cos (5\theta - 8^\circ) + 0.86 \cos (7\theta - 67^\circ) + 0.23 \cos (9\theta + 55^\circ)$$



[C. M. DAVIS]

FIG 5.—WAVE SHAPE ILLUSTRATING A VERY BAD DISTORTION RATIO
Distortion ratio = 1.92

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power factor and consuminga voltage three or four times that at the condenser terminals. The distortion ratio is the fraction

$$\frac{\text{true condenser-reactance}}{\text{condenser reactance on distorted wave}}$$

Measurements of wave shape distortion on apparatus should be made at full voltage and no-load.

APPENDIX

DERIVATION OF DISTORTION RATIO

Let x_0 = true reactance of condenser

n = order of the harmonic

E_n and I_n = max. values of voltage and current respectively of the nth harmonic

E and I = effective values of the distorted wave.

x_c = apparent reactance of the condenser on the distorted wave.

δ = distortion ratio

a = amplitude constant of the harmonics

m = the number of harmonics present above the fundamental

Then:

$$I_n = \frac{n\,E_n}{x_0}$$

$$E = \sqrt{\tfrac{1}{2}\,\Sigma\,E_n^2}$$

$$I = \sqrt{\tfrac{1}{2}\,\Sigma\,I_n^2}$$

$$x_c = \frac{E}{I}$$

and

$$\delta = \frac{x_0}{x_c}$$

If

$$E_n = \frac{a}{n}\,E_1$$

$$I_n = \frac{n\,E_n}{x_0} = \frac{a\,E_1}{x_0}$$

$$I = \sqrt{\tfrac{1}{2}\left(I_1^2 + m\frac{a^2 E_1^2}{x_0^2}\right)}$$

$$= \frac{E_1}{x_0}\sqrt{\tfrac{1}{2}\,(1+m\,a^2)}$$

$$E = \sqrt{\tfrac{1}{2}\left(E_1^2 + \frac{a^2}{n^2}E_1^2 + \ldots\text{.to } \boldsymbol{m} \text{ harmonics}\right)}$$

$$= E_1\sqrt{\tfrac{1}{2}\left\{1 + a^2\left(\Sigma\frac{1}{n^2}\right)\right\}}$$

$$x_c = \frac{E}{I} = x_0\sqrt{\frac{1 + a^2\left(\Sigma\frac{1}{n^2}\right)}{1 + m\,a^2}}$$

and

$$\delta = \sqrt{\frac{1 + ma^2}{1 + a^2\left(\Sigma\frac{1}{n^2}\right)}}$$

from which

$$a = \sqrt{\frac{\delta^2 - 1}{m - \delta^2\left(\Sigma\frac{1}{n^2}\right)}}$$

STRAY LOSSES IN INDUCTION MOTORS

BY

A. M. DUDLEY

Presented under the auspices of the

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STRAY LOSSES IN INDUCTION MOTORS

BY A. M. DUDLEY

ABSTRACT OF PAPER

This paper calls attention to the fact that " load losses " on induction motors as described in Section 167 of the present Standardization Rules include some losses which are not actually present when the motor is running under normal operating conditions. An analysis is made of the cause and nature of the so-called load losses and a suggestion is made as to a method of segregating the real load losses from other losses as observed in the power input to the motor at standstill. The conclusion is drawn that motors up to a certain capacity with wire windings have no appreciable load loss. In larger capacities and with conductors of certain types load losses are present.

Recommendation is made that Section 167 be revised so as to include a method of determining the load losses of all classes of motors from readings taken at standstill. This will permit the calculation of the true efficiency from no-load and standstill readings.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26–28, 1913.

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STRAY LOSSES IN INDUCTION MOTORS

BY A. M. DUDLEY

Section 167 of the Standardization Rules, referring to induction motors, states, "These losses (load losses) may for practical purposes be determined by measuring the total power, with the rotor short-circuited at standstill and a current in the primary circuit equal to the primary energy current at full load. The loss in the motor under these conditions may be assumed to be equal to the load losses plus I^2R losses in both primary and secondary coils."

It is the purpose of this paper to point out that the losses as measured according to this section in many cases include losses which are not present when the motor is operating at normal full load speed and which cannot, therefore, justly be called load losses and charged against the efficiency of the motor as calculated by the " summation of losses " method.

It is the further purpose to point out a method by which the separate losses in a motor, including the load losses, may be segregated from no-load readings with reasonable assurance that the motor efficiency as figured therefrom will be as close to the efficiency measured by the input-output readings when the motor is running under load as is the limit of error necessarily encountered in taking these readings even under laboratory methods.

The reason for presenting the problem as it is stated in the last paragraph appears from a consideration of the practical difficulties encountered in testing units of such a size as to make it difficult to secure facilities for running an actual load test either on the premises of the manufacturer or after installation in regular service.

The limitations of the manufacturer in this case are usually (a) lack of mechanical apparatus for connecting the motor to a suitable load, (b) lack of a suitable load either mechanical or in the nature of an electrical generator, and (c) insufficient power to operate the unit when developing full load.

The limitations of the ultimate user which act against a successful test after installation are (a) inability to control the load within reasonable variations while observations are being taken; (b) lack of proper facilities in the way of precision instruments and other appliances for suitably conducting such tests, and (c) lack of a sufficient number of properly trained observers for taking the readings.

Added to the foregoing disadvantages is the further one, pointed out in Mr. Olin's paper in the June, 1912, PROCEEDINGS, that errors in observations on load tests, or so-called input-output tests, reduce their reliability below that obtained by making a careful determination of the separate losses from no-load readings and determining the efficiency by the "summation of losses" method.

Recognizing these facts, it has become standard practise on induction motors of small and moderate capacities to compute efficiencies in the following manner: A reading is taken of the amperes and watts input to the motor at full voltage when running idle. From this is subtracted the I^2R losses due to the no-load current and the remainder is considered to be the friction and windage plus the " rotation loss " or so-called " core loss." There is a slight error in the last item due to the fact that the " core loss " should be taken at the induced rather than at the applied voltage, but in all but very small units this error is small. To the foregoing losses are added the primary copper loss at proper full load current and temperature, and the secondary copper loss as shown by full load " slip " from synchronous speed, measured by brake. These total losses are added to the output at the current chosen and the result considered the input and the efficiency computed therefrom.

So soon, however, as the unit becomes of a size where it is difficult or impossible to take the slip under actual load, a question immediately arises as to the amount of the secondary copper loss. When recourse is had to Section 167 of the Standardization Rules quoted above, it offers no means of segregating the load losses from the secondary copper loss after the primary copper loss has been subtracted from the watts input to the motor at standstill at normal voltage.

It is this uncertainty that makes necessary an analysis of the nature of these so-called load losses and the outlining, if possible, in the Standardization Rules of the Institute, of a method for segregating this loss from the other losses in the machine.

A consideration of the possible causes of such losses suggests two sources:

a. A distortion of the main field form due to armature reaction caused by working load currents, or

b. Eddy currents in the copper conductors due to the main field.

On account of the symmetry of the core and distribution of the windings it may safely be assumed that there is very little if any, distortion of the field form, due to this cause, and any loss so set up may be neglected.

There remains the eddy currents in the copper due to the main field.

It is here to be noted that with the rotor at standstill and a current of normal frequency flowing in the primary, the frequency of the secondary current is the same as that of the primary. At normal full load speed, however, the frequency of the rotor is very low, being only the same percentage of the primary frequency that the slip is in percentage of synchronous speed. From this it follows at once that where the cross-section of the rotor conductors is such as to permit setting up of eddy currents there may be a very appreciable proportion of the watts at standstill due to eddy currents in the rotor copper which are not present when the rotor is running up to speed.

Added to this item is one of less consequence, due to iron loss in the secondary at standstill which is not present at full speed.

It is, therefore, proper to charge against the motor the eddy current losses in the primary copper but exclude those due to eddy currents in the secondary copper. To get at a method of approximating these losses more closely a series of readings was taken on a motor with currents of varying frequency in the primary windings. These results are shown in Fig. 1. From these readings it appears that as the frequency approaches zero the watts input becomes very nearly that due to the copper losses in primary and secondary caused by usual resistances of the windings alone. There still remains the question of segregating the increased loss at normal frequency into eddy current loss in the primary and secondary so that the machine need not be charged with a loss occurring in the secondary at standstill which is not present at full speed.

There are, no doubt, several ways in which this could be accomplished, of which two may be mentioned here.

1. The increased losses over the ordinary I^2R losses as shown in Fig. 1 may be divided into primary eddy current loss and secondary eddy current loss, in proportion to the square of the depth of the conductor in the slot in each member. This is, in a way, somewhat empirical, but it would probably give as close results as can be arrived at by other methods, and it has the advantage of being simple, since the details of design are usually readily available when conducting tests.

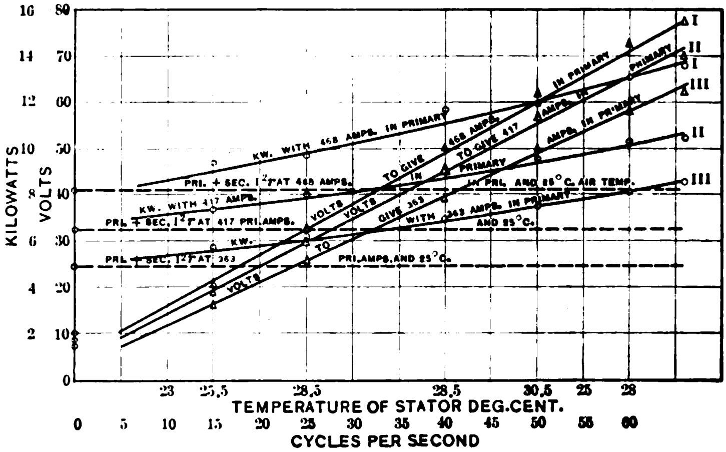

FIG. 1—VARIATION OF EDDY CURRENT LOSSES IN PRIMARY AND SECONDARY COPPER WITH VARIATION IN FREQUENCY

Induction motor, 450 h.p. three-phase, 60 cycles, 440 volts. 8 poles, 870 rev. per min.
Rotor resistance at 25 deg. cent. 0.314$^{\omega}$ terminal to terminal.
Stator resistance at 25 deg. cent., 0.128$^{\omega}$ terminal to terminal
Readings taken with secondary short circuited and locked. Amperes in primary are read per phase.

2. The rotor if of the phase-wound type, could be removed from the stator and sufficient voltage applied to its terminals to cause full load current to flow in the windings. A measurement of the watts input under this condition as compared with the straight I^2R due to the resistance of the windings would indicate the amount of the eddy current loss in the secondary copper and this should be deducted from the total watts input to the machine at standstill. The remainder should be charged against the machine as the usual I^2R loss in the primary and secondary

plus the proper load loss due to eddy currents in the primary conductors caused by the main field.

At this point it might be brought out that the value of the secondary current at full load may be taken from the Heyland diagram or some modification thereof, or it may, for all practical purposes, be taken from the following formula: Secondary current per terminal at full load = horse power output in watts + secondary I^2R loss + bearing friction and windage ÷ K × volts between collector rings at standstill with normal voltage applied to the primary. $K = 1.73$ for three-phase rotor and $= 2$ for two-phase rotor.

In the case of a squirrel-cage motor the rotor could be removed from the stator and sufficient voltage applied to the terminals of the stator to cause full load current to flow therein. A measurement of the watts input under this condition as compared with the straight I^2R loss would indicate the amount of eddy current loss in the primary copper. This amount, added to the ordinary primary and secondary copper loss determined by the method shown in Fig. 1, would indicate the proper copper loss to be charged against the machine.

The foregoing discussion has reference to units of fairly large capacity. A careful study of smaller machines, where the size of the primary conductors does not exceed a No. 10 round wire, shows that there are practically no load losses. It is not necessary to burden this paper with a long tabulated statement of the data investigated to prove this point, but a brief statement will cover the results of this investigation.

Sixty-nine motors were selected, entirely at random. They were of both the wound rotor and squirrel-cage types, open and closed slots, 60 and 25 cycles, two-and three-phase, voltages from 220 to 2,200 and capacities from 3½ h.p. to 150 h.p. A comparison was made of the full load efficiencies as determined by careful prony brake tests, with the efficiencies by summation of losses. In the efficiencies by losses, no item was entered for load losses. The only losses considered were primary and secondary I^2R losses, the rotational or core losses and the mechanical losses due to bearing friction and windage. It was assumed that if there were any load losses the efficiency by brake test would be consistently lower than by losses. Such was not found to be the case. Out of 69 machines the efficiency by brake test was higher in 34 cases; the efficiency by losses was higher in 32 cases and the two were the same in three cases. From these data, and an experience over a period of several years covering a large number of machines, the conclusion is drawn that for machines in which the primary conductor does not exceed in size a No. 10 wire, B. & S. gage, it may be assumed that there is no load loss or that it is negligible in amount.

Based upon the foregoing argument, the recommendation is made that Section 167 be modified to cover two conditions:

1. That it be recognized that machines having primary conductors of small cross-section have no appreciable load loss, and that a summation of loss method based upon the usual I^2R losses measured by resistance and slip is sufficiently accurate for determining their efficiency.

2. That on machines having primary conductors of comparatively large cross-section and consequently some load loss in the primary copper, a method be approved for determining the efficiencies from no-load readings, substantially as described in this paper.

METHODS OF DETERMINING TEMPERATURE OF TRANSFORMERS AND OF COOLING MEDIUM

BY

S. E. JOHANNSEN and G. W. WADE

Presented under the auspices of the

Standards Committee

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METHODS OF DETERMINING TEMPERATURE OF TRANSFORMERS AND OF COOLING MEDIUM

BY S. E. JOHANNESEN AND G. W. WADE

ABSTRACT OF PAPER

The paper discusses methods of determining the effective temperature of the cooling medium and the actual temperature of heated transformers. Particular attention is called to the errors resulting from variations in the temperature of air during a heat run on a self-cooled oil-immersed transformer because of the slowness of the large mass of material in following changes of temperature in the surrounding medium. It is pointed out that the effective temperature of the cooling medium is practically the average temperature of a duplicate transformer, subjected to the same cooling conditions and without load. This temperature should be used as the base for calculating rises.

Methods of measuring hot temperatures by rise in resistance are discussed. Attention is called to the advantages obtained by comparing resistance of the loaded transformer with that of a duplicate idle transformer.

The cooling of windings after load is removed, but before resistance readings are obtained, causes an error in the determination of the temperature rise. This drop in temperature can be avoided by measuring the resistance of the windings without cutting off the load. A method of doing this is described.

Actual test results are given to show the advantages gained by using a duplicate idle transformer as a base for determining temperature rises. Instructions for using such an idle unit are also given. The paper ends with recommendations for additions to the rules to the effect that duplicate idle transformers be used whenever possible as a base for determining temperature rises.

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METHODS OF DETERMINING TEMPERATURE OF TRANSFORMERS AND OF COOLING MEDIUM

BY S. E. JOHANNESEN AND G. W. WADE

Of all measurements applied to transformers, none are so difficult to duplicate and to obtain accurate and consistent results from, as tests for determining temperature rise. There are a great many different conditions to be controlled or corrected for in case of variation. The difficulties are principally due to the four following causes:

1. Variations in load, including voltage, current and frequency.
2. Variations in the cooling medium with regard to its condition, its temperature, and the quantity supplied in case of artificial cooling.
3. Inaccuracies in the measurement of the effective temperature of the cooling medium.
4. Inaccuracies in the measurement of hot temperatures.

The first and second of the above causes are not within the province of this paper, but the other two will be taken up in the above order after a short discussion of the measurement of temperature.

THERMOMETERS

Temperatures are usually measured by means of mercury thermometers, although other types are sometimes used for special purposes.

Mercury thermometers are made for various ranges of temperature and for various degrees of accuracy. Other things being equal, the shorter the range the higher the degree of accuracy. It is desirable, therefore, to select a thermometer having a range just sufficient to include all the temperatures to be measured. For air temperatures a range from about 0 to 50 deg. cent.

is most suitable while a wider range, say from 0 to 100 deg. cent. is usually necessary for determining hot temperatures. For such ranges mercury thermometers can be made for an accuracy of about 0.01 deg. plus or minus, but these are too expensive and too fragile for ordinary use. The cheapest form has an accuracy of about 1 deg. plus or minus. Mercury thermometers are best suited for the determination of temperatures of air, tanks, and other iron parts. They should not be used in strong magnetic fields on account of the heating due to eddy currents induced in the mercury. It is preferable not to use them inside the transformer case unless the bulb is very carefully protected, since short circuits may be caused by the mercury falling on the coils or leads in case the bulb is broken.

Spirit thermometers are most suitable for obtaining temperatures of coils or oil as they are not affected by magnetic fields and as no bad results will be caused by their breakage. They are not as accurate or as reliable as mercury thermometers and it is necessary to calibrate them for the condition under which they are to be used in order to obtain correct readings. For instance, one calibrated with a 5-cm. immersion of the bulb in oil would not give accurate results when used totally immersed. With proper calibration, however, they have an accuracy of about 1 deg. plus or minus in the 0 to 100 deg. range.

Capillary tube thermometers are useful for determining temperatures at a distance below the oil surface. They have about the same degree of accuracy as spirit thermometers but are much more expensive. Care should be exercised to keep them away from the coils and leads.

Resistance thermometers are very useful for determining temperatures at points inaccessible to the other types. They can be made with a higher degree of accuracy than capillary tube type but are somewhat more expensive.

Great care is needed placing the thermometers so as to determine the temperature of the flat surfaces, such as tanks, cores, and coils. It is best to cover the bulb entirely with some material such as putty, so as to give a good surface contact and to keep the bulb from the influence of air currents on the side away from the surface. Cotton waste may be used for this purpose, but it is not quite as desirable as putty or some substance of the same nature, because it does not entirely prevent air currents from coming in contact with the bulb. For measuring temperatures between coils of air-blast transformers, a good method is to use cork. A hole large enough to allow the thermometer bulb to be inserted should be drilled into the cork, after which it should be cut away on one side so as to leave a part of the surface of the bulb exposed, this exposed surface being set against the coil. The cork should be cut wedge-shaped with a pointed bottom, so that it will not impede the flow of the cooling medium.

Effective Temperature of Cooling Medium

As the measurement of this temperature depends to a great extent upon the method of cooling, we will take up the various methods in their order, beginning with the oil-immersed self-cooled type.

If the room temperature is kept absolutely constant throughout a heat run, its actual temperature is the effective reference base. Mercury thermometers placed in the air or in small oil cups are entirely satisfactory for the determination of this temperature. The precautions mentioned in the Standardization Rules, section 263, should be observed:

> "The thermometers indicating the room temperature should be protected from thermal radiation emitted by heated bodies, or from drafts of air, or from temporary fluctuations of temperature. Several room thermometers should be used."

As the above rule does not state that a constant room temperature is required, it may be inferred that a varying room temperature is permissible, and that the effective room temperature is the air temperature at the end of the run. Such an interpretation as this may not cause errors in the determination of rise on air-cooled apparatus but it does cause very serious errors in tests of oil-immersed transformers. The realization of this source of error has given rise to various methods of determining the effective room temperature, such as:

1. Average room temperature over several hours preceding the end of the run.
2. Final room temperature measured by thermometer in a small oil bath.
3. Average room temperature by means of oil bath for several hours preceding the end of the run.

The oil bath referred to is a small vessel filled with oil. The most commonly used is probably that standardized by the United States Navy, which consists of a steel cylinder 7.6 cm. long and 5.1 cm. in diameter, into which is drilled a hole 1.27 cm. in diameter and 3.8 cm. deep.

None of the above methods give the effective room temperature (except accidentally) because they do not take into account the fact that different transformers are affected to different degrees by varying air temperatures. Oil-immersed transformers are extremely slow in following changes in the temperature of the cooling medium. Their slowness varies directly with the size, which is a measure of thermal capacity or power of retaining heat and inversely as their radiating ability, which is a measure of the power of dissipating heat. The thermal capacity of oil is very high, its specific heat being in the neighborhood of 0.40. The slowness of a transformer in following changes of air temperature is also noticed when it is heating up under load. The following table shows the approximate time required by several representative self-cooled, oil immersed transformers to reach various percentages of their ultimate temperature rise when heated up on normal load.

Size of transformer	Per cent of final temperature rise		
	60	90	99
2 kv-a.	2 hr.	5 hr.	10 hr.
15 "	4 "	10 "	20 "
40 "	5 "	12 "	24 "
500 "	6 "	13 "	26 "

It will be easily seen from the above that the only accurate method of correcting for varying room temperatures is by means of some device which produces a lag behind the air temperatures corresponding in degree and in phase with the lag of the heated transformer. Since each design has its own rate of lag it is evident that a different device is needed in each case. The most satisfactory device which has been found is another transformer of the same design, preferably a duplicate of that under test. This auxiliary or idle unit should, of course, be without load and subjected to the same cooling medium as the heated transformer. Since its mass and working parts are the same as the one under test, it must of necessity be affected by varying room temperatures in exactly the same way as the heated transformer. The only difference between the two is that due to the load, so that the difference of temperature between them must be due entirely to the load.

In oil-immersed transformers, the effective temperature of the cooling medium is the average temperature of the idle unit.

This should be determined by taking the average of the top and bottom oil. If the bottom oil temperature cannot be measured directly, it may be approximated very closely by first measuring the temperature of the top oil, the top tank just under the oil level, and the bottom tank, and then calculating the average oil as follows:

If I_t is the top oil, O_t the top tank, and O_b the bottom tank temperature, the bottom oil is

$$\frac{I_t\,O_b}{O_t}$$

and the average oil temperature is

$$\frac{1}{2}\left(\frac{I_t\,O_b}{O_t}+I_t\right)$$

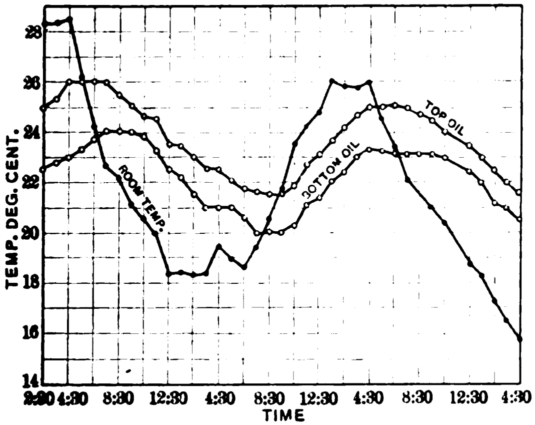

FIG. 1—IDLE TRANSFORMER RUN

185 kv-a., self-cooled, oil-immersed.

Another way in which the average temperature of the idle unit may be determined is to measure the resistance and observe the temperature before the oil is put in. Then whenever the average temperature is desired, the resistance should be measured and the temperature calculated. It is considered best, however, to use this calculated temperature merely as a check upon the temperature observed by thermometers.

Fig. 1 and Table I show the hourly readings of temperature of top and bottom oil of a 185 kv-a. idle transformer compared with room temperatures over a period of 24 hours during which the air had a total variation of approximately 10 deg. Attention is called to the corresponding cycles of the temperatures, especially to the fact that the oil cycle lags several hours behind the air in time phase and has much smaller maximum and minimum peaks than the air temperature. The bottom and top oil

TABLE I.

IDLE UNIT RUN, 185 KV-A., SELF-COOLED, OIL-IMMERSED TRANSFORMER

Hour	Room Temperature	Oil temperatures	
		Top	Bottom
	deg. cent.	deg. cent.	deg. cent.
2:30 p.m.	28.2	24.9	22.5
3:30	28.3	25.3	22.8
4:30	28.4	26.0	23.0
5:30	26.2	26.0	23.3
6:30	24.2	26.0	23.7
7:30	22.6	26.0	24.0
8:30	22.2	25.5	24.0
9:30	21.1	25.0	24.0
10:30	20.5	24.6	23.8
11:30	19.9	24.5	23.2
12:30 a.m.	18.3	23.5	22.5
1:30	18.4	23.4	22.2
2:30	18.2	23.0	21.5
3:30	18.3	22.5	21.0
4:30	19.4	22.5	21.0
5:30	18.9	22.0	21.0
6:30	18.6	21.8	20.6
7:30	19.4	21.6	20.0
8:30	20.5	21.5	20.0
9:30	21.6	21.5	20.0
10:30	23.5	21.8	20.3
11:30	24.3	22.7	21.1
12:30 p.m.	24.9	23.1	21.3
1:30	26.1	23.7	22.0
2:30	25.8	24.2	22.4
3:30	25.9	24.7	23.0
4:30	26.0	25.0	23.3
5:30	24.6	25.0	23.3
6:30	23.5	25.1	23.2
7:30	22.1	25.0	23.2
8:30	20.6	24.8	23.2
9:30	21.1	24.5	23.1
10:30	20.5	24.0	23.0
11:30	——	——	——
12·30	19.7	23.5	22.5

follow the same curve, the difference in temperature between them being nearly constant. The bottom oil seems to have a slight tendency to start downward later than the top oil when the room temperature is decreasing and to start upward earlier than the top oil when the room is increasing. This is probably due to the fact that the room reaches the temperature of the bottom oil later when decreasing and earlier when increasing. The following tabulation of average values for a period of 24 hours is rather interesting.

Average air temperature	22.45 deg.
“ top oil “	23.65 deg.
“ bottom oil temperature	22.05 deg.
“ top and bottom oil temperature	22.85 deg.

The average of the top and bottom oil is 0.4 deg. higher than the average air, but since this is within the range of accuracy of the thermometers used, no attempt will be made to explain it.

The conclusion that the idle unit and the heated transformer are affected in exactly the same way by varying air temperatures is based on the supposition that the coefficients for emission and absorption of heat are exactly the same and that the heat given out is directly proportional to the temperature rise. This is so nearly true for tank surfaces within the range of transformer operation that the errors introduced due to such an assumption are negligible.

In the case of water-cooled transformers, the problem is complicated by the fact that we have to consider two cooling mediums instead of one. The water remains practically constant over any period of time usually needed for a heat run so that no corrections for variations in the temperature of the water during the run need be considered. Some method of correcting for variations in air temperature during the run is desirable, but these variations have only a slight effect on the temperature of the hot unit because the greater part of the heat is carried away by the water. Consequently no serious error in the temperature rise will be introduced by considering the ingoing water as the true reference base. There is, however, a small error and it is possible that the idle unit may serve to eliminate it, or at least to give more nearly correct rises than the ingoing water temperature. We have not yet been able to obtain sufficient data on this subject to prove that the idle unit gives more nearly the effective temperature of the cooling medium than the ingoing water. In the absence of such proof, it is best to continue past practise of using the ingoing water as the base. The errors caused by such practise will depend on the relative quantities of heat dissipated by the two cooling mediums. If all of it were taken by the water, no attention need be paid to the air temperature. However, the air does take from 10 to 30 per cent ordinarily so that the effective base is somewhere between the temperature of the water and that of the air.

Air-blast and air-cooled transformers follow changes in air temperature much more closely than do the oil-immersed types because their thermal capacities are considerably smaller. The ingoing air temperature may be taken as the effective base, precautions being taken to guard against sudden fluctuations. A small oil cup will serve to prevent errors due to small and sudden changes in the air and will also have a slight lag behind the air, corresponding approximately to that of the transformer.

METHODS OF MEASURING HOT TEMPERATURES

Hot temperatures should always be determined by resistance as well as by thermometers.

Thermometers should be placed so as to indicate the temperature of the hottest part. In oil, immersed transformers this is usually the top oil directly over the coils. In water, cooled units care must be taken to keep the thermometer away from the cooling coils as the oil is much cooler in that vicinity, the coldest oil being between the cooling coils and the tank. In air cooled transformers the hottest point is usually near the top of the coils and the thermometers should be placed at a number of different points on the coils so as to find this maximum.

Hot resistances may be measured by any one of the four following methods:

1. Voltmeter and ammeter.
2. Potentiometer.
3. Wheatstone bridge.
4. Kelvin or Thompson double bridge.

For such resistances a method giving quick readings is essential as considerable error may be introduced by the cooling of windings after the load is taken off and before the resistances are measured. The quickest readings can be obtained by the voltmeter and ammeter method for which reason its use is recommended except for very high or very low resistances. For high resistances this method requires a very high voltage in order to produce an appreciable current, and unless the voltmeter has a high resistance itself, a large correction factor is required on account of the large part of the current taken by the voltmeter. The potentiometer or the Wheatstone bridge although less rapid than the voltmeter and ammeter method, are better for the high resistances. For low resistances the voltmeter and ammeter method is not desirable because of the very large current required to produce a voltage which can be accurately measured. The Wheatstone bridge method is not accurate for such use because its resistances include leads and contacts which are a large proportion of the total resistance in such cases. The potentiometer avoids these errors and it is therefore recommended for measurement of low resistances.

In using the voltmeter and ammeter method, care must be taken to avoid including the resistance of leads and contacts. This can be done by carrying separate leads to the voltmeter and to the ammeter and attaching them at different points on the transformer leads. If the voltmeter takes an appreciable part of the total current supplied, this part should be subtracted from the measured current before the resistance is calculated. In applying the direct current an induced counter e.m.f. lowers the voltmeter reading for a time. This induced e.m.f. gradually disappears but is objectionable because it delays the reading of the voltmeter. It can be caused to decrease more rapidly by raising the current at first to a value about 10 or 15 per cent in excess of that desired and then bringing it down slowly. It may be entirely eliminated in a winding provided with a middle tap or divided into two equal parts by applying the direct current in opposite directions through the two halves as shown in Fig. 2.

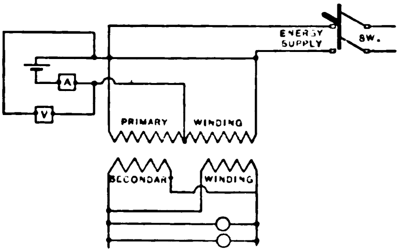

FIG. 2—APPLYING DIRECT CURRENT SO AS TO NEUTRALIZE INDUCTIVE EFFECT

In using the Wheatstone bridge the resistance of the leads from the bridge to the transformer must be subtracted from the observed value.

In determining rise by resistance by means of the voltmeter and ammeter method, the idle unit if it is a duplicate of the heated unit, is of considerable value when used as follows: The resistance of the two units should be compared before a heat run, care being taken to see that they are at the same temperature. The corresponding windings should be connected in series and with current forced through them the drop across each should be measured. The hot resistance of the unit under test should be compared with that of the idle unit, measurement being made in the same way as before. The rise by resistance should be calculated directly from these comparative voltmeter readings. If there is a difference between the initial resistances of the two units, a correction should be made before calculating the rise by multiplying the final resistance of the idle unit by the ratio of the initial resistances of the heated unit to the idle unit, or to put.in the shape of a formula, we have

$$\text{Temp. rise} = \left(\frac{V_3 \times V_2}{V_4 \times V_1} - 1\right)(233.8 + T_1)$$

where

V_1 = initial resistance voltage of loaded transformer
V_2 = “ “ “ “ idle “
V_3 = final “ “ “ loaded “
V_4 = “ “ “ “ idle “
T_1 = “ temperature “ “ “

and 233.8 = the inferred absolute temperature of resistance.

This method eliminates practically all errors due to any changes in the instruments between the measurement of the cold and the hot resistance. Errors in ammeter readings can have no effect since the same current is sent through both transformers. It is not necessary to know the actual temperature corresponding to the cold resistance because all that is needed is the comparative value when the two are at the same temperature. The final temperature of the idle unit need be known only approximately as its temperature is the effective base and the only error caused by a mistake in reading this temperature is that due to the use of a slightly incorrect temperature coefficient.

The amount of current to be used in measuring resistance should be chosen so as not to cause any appreciable heating due to I^2R when the cold resistances are measured. This means that the direct current should not ordinarily exceed 15 to 20 per cent of the rated current of the winding.

When resistances are very low, 0.001 ohms or less, it is usually difficult to obtain accurate measurements. Consequently, it is preferable to depend upon the temperature shown by thermometer or by resistance of the other winding.

EXPLORING COILS

The rise by resistance shows only the average temperature of the winding. It is sometimes considered desirable to ascertain temperatures at points where it is suspected that the values will be considerably above the average. This can be done by means of small exploring coils. It is also desirable in some cases to determine the temperature of the windings without cutting off the load. This may be accomplished by means of a small exploring coil which measures a local temperature, or by means of a distributed coil which extends through a large part or all of the transformer winding.

The first form which may be called a local exploring coil is usually wound on some insulating material, and is thoroughly insulated from the main winding. The other form or distributed coil may be wound turn for turn with the transformer winding. It should be grounded to the transformer winding at one point and carefully insulated elsewhere. Either form of coil should be wound non-inductively so that the alternating current will not affect the readings or cause high induced voltages.

In general, the differences in local temperatures are not large enough to warrant the use of local exploring coils except in laboratory investigations. It is desirable to know the temperature of coils when transformers are in actual operation, but the advantage gained is not considered large enough to compensate for the added element of danger, due to the presence of exploring coils in the windings.

COOLING OF WINDINGS

Mention has been made of the cooling of the windings after load is removed. As a matter of fact the whole transformer cools but the rate is very slow in the case of oil-immersed types. The thermal capacity of the coils, however, is much less than that of the other parts and as a result, the windings cool to the average temperature much more quickly than the entire transformer cools to the air or cooling medium. For instance, the thermal capacity of the copper of a certain 185 kv-a. transformer is about 98,000 joules while that of the oil is about 2,200,000 joules. The rate of this cooling of windings may be calculated as follows:

The windings are at a constant temperature rise above oil before the load is taken off so that the rate at which they are giving out heat is the same as the rate at which energy is being put into them, or in other words it is the copper loss. This rate continues for a short period after the load is taken off. The thermal capacity of a pound of copper is about 177 joules. Then, if the coils are giving out heat at the rate of one watt per pound, (0.45 kg.) one joule will be lost during the first second after shut down. This will cool the coil 1/177th of a degree in the first second, and 60 times this amount, 0.342 deg. in the first minute. At three watts per pound (0.45 kg.) the cooling the first minute would be approximately 1.04 deg. These values will be modified to some extent by the fact that the insulation of the coil has a certain thermal capacity, thus increasing the total value and decreasing the rate of cooling. This rate decreases as the coil comes nearer and nearer to the oil temperature, reaching the zero value when the rise above oil becomes zero. The curve of temperature against time is logarithmic in shape, the rate of cooling at any point being proportional to the rise above the base temperature. The total time of cooling varies with the design but in ordinary cases it is between 30 and 60 minutes. We are interested mostly in the first minute or two, and during this period there is very little change in the rate. If the watts loss per pound of copper is known, an approximate correction can be made by calculating the initial rate, noting the time at which the resistance reading is obtained and multiplying this time by the rate, finally adding this to the measured temperature rise. This correction is, however, only approximate and should not be applied for periods of more than a few minutes. Another method which gives more accurate results is to take readings of resistance over a period of six or eight minutes so as to determine the shape of

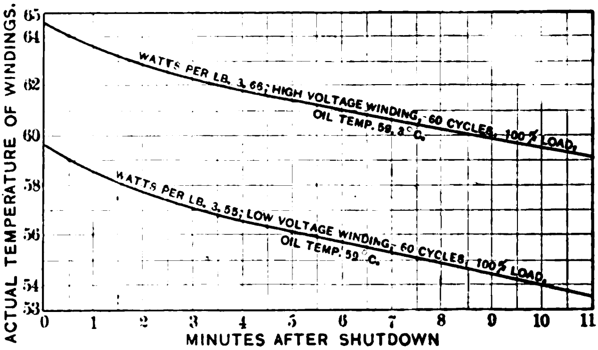

FIG. 3—COOLING CURVES OF WINDINGS
100 kv-a., self-cooled, oil-immersed transformer.

the cooling curve then prolong the curve so as to show the initial resistance. This method has the disadvantage that it allows the transformer to cool considerably and thus prolongs the heat run in case any further measurements are desired such as the rise by resistance of the other winding.

Representative cooling curves of windings of self-cooled oil-immersed transformers are shown in Figs. 3 and 4.

The rate of cooling of windings in air-blast transformers is lessened considerably if the air is shut off simultaneously with the load. In fact it is quite often found that the thermometers on the coils indicate an increase in temperature for the first few minutes. This is probably because the shutting off of the air supply leads to an equalization of temperature throughout the coils, thus reducing the higher and increasing the lower temperatures.

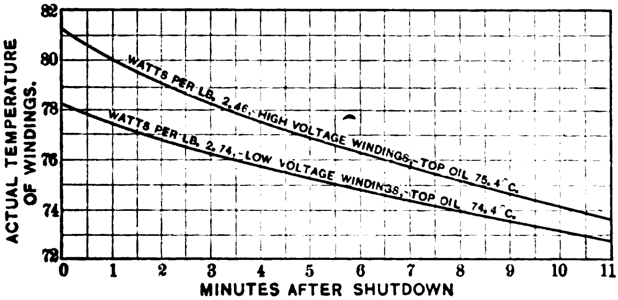

FIG. 4—COOLING CURVES OF WINDINGS
100 kv-a., self-cooled, oil-immersed transformer.

MEASURING RESISTANCE WITHOUT CUTTING OFF LOAD

Resistance of windings having a middle tap or divided in two equal parts may be measured while the load current is passing through them by the method shown in Fig. 5. This figure shows the ordinary connections for bucking run on two transformers each of which is provided with a middle tap in each winding. The excitation or core loss voltage is applied to the two high-voltage windings connected in multiple while the copper loss is supplied in series with the two low-voltage windings. When it is desired to measure the resistance of the high-voltage windings in this case the direct current is applied to the middle points of the two windings between which there is no difference of potential due to the alternating current. The direct current flows in opposite directions in the two halves, thus neutralizing its own inductive effect. The measured resistance is that of the two windings in multiple. It will be noted that this measurement can be made without disturbing the heat run connections or losses in any way.

It is usually considered desirable, however, on account of safety to cut off the excitation or core loss supply while the direct current instruments are being read.

The middle points of the low voltage windings shown in the figure are not at the same potential, because of the unbalancing due to the copper loss supply voltage which is in series with them. This makes it necessary to provide an auxiliary or equalizing coil so as to provide an artificial middle point. This equalizing coil may be one of the windings of a similar transformer. The measured resistance is that of the two halves of the equalizing coil connected in multiple with the two halves of the loaded transformer. The actual value of the resistance of the transformer may be calculated after the resistance of the equalizing coil alone has been measured.

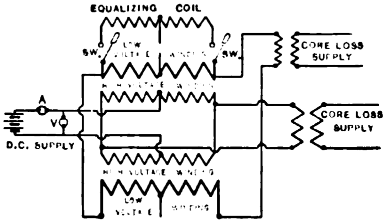

FIG. 5—METHOD OF MEASURING RESISTANCE WITHOUT CUTTING OFF LOAD

This method is too complicated for general use, but is desirable where it is not convenient to cut off the load for resistance measurements and where a large error would be caused by cooling of windings. It has several advantages over the old method among which the following may be mentioned.

1. It makes it possible to measure resistance as often as desired without lengthening the heat run.

2. It eliminates drop in temperature due to cutting off load while measuring resistance.

HEAT RUN WITH IDLE UNIT

Fig. 6 and Table II give a record of a heat run on a 500 kv-a. oil-immersed self-cooled transformer; temperatures of top oil of idle unit, top oil of heated unit and of surrounding air being shown each hour during a period of about four days. The comparative rises of the heated unit above air and above the top oil of the idle unit have also been plotted. Particular attention is called to the wide variation in room temperature as compared with the top oil temperature of the two transformers. Each of the three curves show cycles corresponding to 24-hour periods. The oil temperature cycles lag several hours behind the air, those of the idle unit being practically in phase with those of the hot unit. The cycles of rise above air are the reverse of those of air temperature and have about the same range of temperature. The rise above the top oil of idle unit also shows faintly cycles in phase with those of the rise above air, but the variations in the value of this rise are considerably less than those of the rise above air. The fact that these cycles are in phase with the rise above room indicates that the idle unit does not entirely compensate for variations in air temperatures, or in other words, that it is not affected to as great an extent as the heated unit by such variations. This may be true, but even if it is, the test shows that the idle unit gives far more consistent results than any other method so far suggested. The approximately correct temperature rise may be determined by calculating the rise above room each hour for a complete cycle of 24 hours after ultimate rise is reached and averaging the result. This method, although too expensive for general use, is useful in some cases and gives some interesting data in this case.

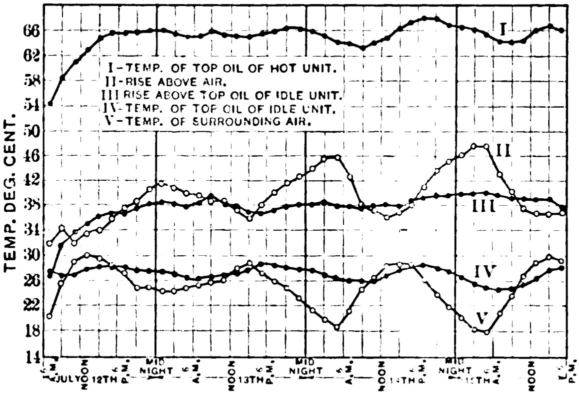

FIG. 6—HEAT RUN ON TRANSFORMERS
500 kv-a., oil-immersed, self-cooled.

TABLE II.

NORMAL LOAD HEAT RUN ON 500-KV-A. SELF-COOLED OIL-IMMERSED TRANSFORMER.

Day	Hour	Room temperature	Top oil temperatures		
			Loaded transformer	Permanently screened idle transformer	Alternately screened idle transformer
		deg. cent.	deg. cent.	deg. cent.	deg. cent.
July 12	7 a.m.	20.5	54.5	27.5	27 Screened
"	8	23.0	57.5	27.0	26.6
"	9	25.7	58.5	27.0	26.6
"	10	27 5	59.5	27.1	26.9
"	11	29.0	61.0	27.2	27
"	12	29.5	63.0	27.8	27.6
"	1 p.m.	30.0	63.2	28.1	28.0
"	2	30.0	64.0	28.2	28.0
"	3	29.5	64.8	28.6	28.5
"	4	29.0	65.0	28.6	28.5
"	5	28.5	65.7	28.7	28.6
"	6	28.0	65.6	28.5	28.7
"	7	27.5	65.7	28.3	28.8
"	8	26.7	65.7	28.1	28.5
"	9	25.3	65.7	27.9	28.4
"	10	25.0	65.7	27.7	28.2
"	11	25.0	66.0	27.6	28.1
"	12	25.0	66.3	27.5	27.9
July 13	1 a.m.	24.5	66.1	27.3	27.7
"	2	24.5	65.7	27.1	27.6
"	3	23.5	65.5	27.0	27.4
"	4	24.5	64.8	26.8	27.3
"	5	25.0	65.0	26.7	27.3
"	6	25.5	65.2	26.5	27.0
"	7	25.5	65.3	26.6	27.0 Screen removed
"	8	26.0	65.8	26.6	27.3
"	9	26.8	65.9	26.5	28.0
"	10	26.5	66.0	26.6	28.5
"	11	26.5	65.5	27.0	28.9
"	12	27.5	64.9	27.0	29.1
"	1 p.m.	28.0	65.2	27.5	29.8
"	2	28.5	65.2	28.0	29.9
"	3	29.0	65.3	28.4	30.5
"	4	28.5	65.7	28.5	30.8
"	5	27.5	65.7	28.9	31.0
"	6	27.0	66.0	28.7	30.9
"	7	26.0	66.2	28.7	30.9
"	8	25.5	66.4	28.7	30.7
"	9	25.0	66.6	28.4	30.6
"	10	24.0	66.7	29.6	30.3
"	11	23.7	66.4	28.1	30.0
"	12	23	66.3	27.8	30.0
July 14	1 a.m.	21.8	65.8	27.5	29.5
"	2	21.0	65.5	27.2	29.2
"	3	20.0	65.5	27.0	28.8
"	4	19.5	65.0	26.5	28.5
"	5	19.0	64.4	26.4	28.0
"	6	20.0	64.3	26.2	27.8
"	7	21.5	64.1	26.0	27.8
"	8	23.0	63.2	25.9	27.7 Screened

TABLE II.—*Continued.*

NORMAL LOAD HEAT RUN ON 500 KV-A. SELF-COOLED OIL-IMMERSED TRANSFORMER

Day	Hour	Room temperature	Top oil temperatures		
			Loaded transformer	Permanently screened idle transformer	Alternately screened idle transformer
		deg. cent.	deg. cent.	deg. cent.	deg. cent.
July 14	9 a.m.	25.0	63.5	25.9	27.5
"	10	25.5	64.0	26.0	27.6
"	11	27.0	64.5	26.3	27.8
"	12	28.0	64.4	26.6	28.1
"	1 p.m.	29.0	65.3	27.0	28.4
"	2	29.0	65.8	27.2	28.8
"	3	29.0	66.2	27.8	29.3
"	4	29.0	66.9	28.0	29.4
"	5	29.0	67.4	28.8	30.0
"	6	28.0	67.7	28.5	29.7
"	7	26.5	67.9	28.5	29.7
"	8	26.0	68.0	28.5	29.5
"	9	24.0	67.8	28.0	29.0
"	10	22.5	67.6	27.8	28.7
"	11	22.0	67.4	27.5	28.3
"	12	21.0	67.0	27.0	27.8
July 15	1 a.m.	20.5	66.7	26.7	27.5
"	2	19.0	67.0	26.0	27.0
"	3	18.5	66.2	25.7	26.8
	4	18.5	66.0	25.5	26.2
"	5	18.0	65.5	25.0	26.0
"	6	20.0	64.8	24.7	25.5
"	7	21.4	64.5	24.8	25.4
"	8	23.2	64.5	24.8	25.8 Screen removed
"	9	24.2	64.5	24.8	26.0
"	10	25.7	64.5	25.0	26.4
"	11	27.2	64.7	25.4	27.0
"	12	27.7	65.0	26.1	27.8
"	1 p.m.	29.1	66.0	26.8	28.3
"	2	29.2	66.3	27.0	29.0
"	3	30.0	66.8	27.7	29.4
"	4	29.5	66.9	28.1	29.8
"	5	29.3	66.2	28.3	30.2

The following table shows the average value of the five curves in Fig. 6 for two periods of 24 hours each:

Average temperature for 24 hour periods:

1st. day. From 13th at 2.00 P.M. to 14th at 1.00 P.M., incl.
2nd " " 14th " 2.00 " " 15th " 1.00 " "

	1st day	2nd day
Average air temperature..................	24.45 deg. cent.	24.10 deg. cent.
" top oil of idle unit................	27.35 " "	26.60 " "
" " " " hot unit................	65.25 " "	66.15 " "
" rise above air....................	40.75 " "	42.0 " "
" " " idle unit...............	37.85 " "	39.4 " "

	1st day	2nd day
Max. variation of air from average	+4.45 to —5.45	+4.9 to —6.1
" " " idle from average	+1.55 to —1.55	+1.9 to —1.9
" " " hot unit from average	+1.45 to —2.05	+1.85 to —1.75
" " " rise above idle unit from average	+0.65 to —0.95	+1.0 to —1.0
Rise above air from average	+3.80 to —4.45	+5.7 to —5.2

Assuming that the average rise above air is the correct value, which is probably true, it is evident that the rise above top oil of idle unit is in this case between two and three degrees too low. This shows the importance of using the average instead of the top oil as the base temperature. Later tests, one of which is plotted in Fig. 1, show that the average of top and bottom oil for a period of 24 hours is the same as the average air. These tests also show that the top and bottom oil follow the same curve. So the rise above average oil if it had been measured and plotted in Fig. 6 would undoubtedly follow the curve of rise above top oil except that all values would be from two to three degrees higher.

METHOD OF USING IDLE UNIT

The idle unit should be subjected to exactly the same cooling conditions as the heated unit. Care should be taken to place it far enough away so as to prevent its temperature being raised due to the heat radiated from the hot unit. This distance depends upon the size of the unit and the amount of heat radiated. In some cases it is desirable to place a heavy screen between the two units.

Fig. 7, plotted from Table II, shows the effect of screening upon an idle unit placed about 90 cm. away from the heated 500-kv-a. transformer. The hot and the idle units were duplicates, each being placed in a corrugated sheet steel tank of oval shape having floor space of 145 by 89 cm. and a height of 245 cm. They were placed with the long sides next each other. The temperature rise of the oil in the heated unit was in the neighborhood of 40 deg. above the idle unit. It will be noted that the idle unit when unscreened shows a temperature rise of top oil approximately 1.5 deg. higher than when screened. The effect of the hot unit upon the idle unit can be calculated roughly as follows:

The percentage of heat radiated by the hot unit in a corrugated tank is about 25 per cent of the total, the remainder being carried away by convection. This radiated heat is given off in straight lines in every direction. If we should surround the hot unit by means of a screen 90 cm. distant at all points, it would intercept all of the radiant heat. The idle unit does intercept a certain percentage of this heat, which percentage can be calculated by finding the ratio of the area of the idle unit to that of a complete envelope around the hot unit. In the case of the 500-kv-a. unit shown in Fig. 7, this ratio is about 0.15. This means that the idle unit receives 15 per cent of 25 per cent of the total heat dissipated by the hot unit, or 3.75 per cent. The temperature rise of the idle unit will be 3.75 per cent of that of the hot unit which amounts to about 1.4 deg. in this case.

This test is also of interest with reference to the spacing of loaded transformers under test or in operation. If two loaded units, instead of one idle and one loaded, had been used, it is evident that since the two would be at the same temperature, neither could give heat to the other and that the effective radiation from each would be decreased by the amount of heat given to the unscreened idle unit in the test. This would result in a higher temperature rise, amounting to about 1.4 deg. cent. in each transformer.

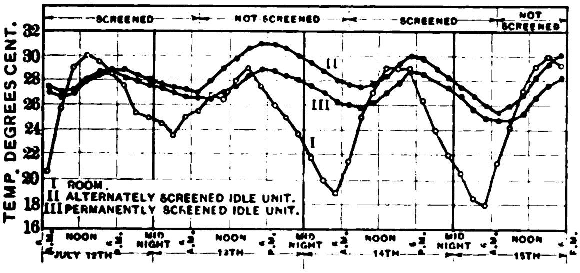

FIG. 7—EFFECT OF SCREENING IDLE UNIT

The temperature of the idle unit may be determined in several ways. If the variations in air temperature are not large, or if the height of the idle unit is small, the top oil temperature will be sufficiently accurate. However, it is preferable to use the average of top and bottom oil temperature, the bottom oil temperature being measured directly when possible. If this is not possible the temperature may be calculated by means of the following formula:

$$\text{Average temperature of idle unit} = \frac{1}{2}\left(\frac{I_t O_b}{O_t} + I_t\right)$$

when

I_t is the top oil temperature
O_t is the top tank tempera ture at oil level
O_b is the bottom tank temperature.

The cold resistance of the idle unit should be carefully compared with that of the unit to be heated up, especial care being taken to have the two at the same temperature or to know the exact temperature of each. This comparison may be made before the oil is placed in the transformer and it is best to make the comparison at this time if the oil temperature differs greatly from that of the room because considerable time will be lost in determining the average temperature of the windings in each unit after they are filled with oil. This comparison of resistances should preferably be made by forcing current through corresponding windings connected in series and reading the drop across each. Several readings should be taken in order to make sure that the exact ratio of the cold resistances has been determined.

The heat run may be started as soon as desired after the above ratio has been measured. It is best not to take readings of resistance until the end of the run, since the load must be taken off, thus causing a drop in temperature. The heat run should be continued until the rise of the top oil of the heated unit above the average idle unit does not change more than one degree in three hours. It may then be considered that the whole transformer is operating at a constant temperature rise. The hot resistance may then be measured and the heat run discontinued.

The hot resistances are to be measured in the same way as the cold, preferably with the same instruments and the same value of current. Since the resistance of the idle unit represents the true effective temperature of the cooling medium, the rise by resistance may be calculated by means of the formula,

$$\text{Temp. rise} = \left(\frac{V_3 \times V_2}{V_4 \times V_1} - 1\right)(233.8 + T_1)$$

where

$V_1 =$ initial resistance voltage of loaded transformer
$V_2 =$ “ “ “ “ idle “
$V_3 =$ final “ “ “ loaded “
$V_4 =$ “ “ “ “ idle “
$T_1 =$ final temperature of idle transformer
and $233.8 =$ the inferred absolute temperature of resistance.

Although the voltmeter and ammeter method is the only one referred to in the above discussion, it is to be noted that the other methods can be used in the same manner with good results, especially where the galvanometer is so constructed as to give quick readings. A potentiometer may be substituted for the voltmeter when a low voltage is to be measured. The bridge methods are well adapted for this use as the two resistance ratios can be measured directly by connecting the idle unit as the known and the loaded unit as the unknown resistance in the bridge circuit.

The advantages of the idle unit for determination of rise by resistance are not restricted to the oil—immersed self-cooled type of transformer. It is equally good for other types regardless of the method of cooling. A slight modification of the method is required in the case of water-cooled oil-immersed transformers if it is desired to use the ingoing water temperature as the base, that is, the rise should be calculated as specified above and then the difference in temperature between the average oil of the idle unit and the ingoing water should be added to the calculated rise. As stated before, we know that the ingoing water temperature is not the effective temperature of the cooling medium unless the air and water are at the same temperature. However, we have not yet obtained sufficient data to justify recommending any other base. No modifications are required for air-blast or air-cooled transformers, as the temperature of the windings is the effective reference temperature.

Recommendations

It is recommended that additions to the Standardization Rules be made as follows:

(1) The effective room or base temperature for an oil-immersed transformer is the temperature of an idle unit similar to and prepared for test the same as that run in test, and its temperature is the average of the top and bottom oil, the bottom oil temperature being measured directly by a thermometer or calculated by multiplying the bottom tank temperature by the ratio of the top oil to the top tank temperature.

(2) When a duplicate transformer is available, the rise by resistance should be determined by first comparing the resistance of the two when at the same temperature, subjecting the idle transformer to the same cooling conditions as the loaded one until hot resistances are to be measured, then comparing the resistances of the two in the same manner as before, and calculating the rise from these final readings, correcting for any difference in the two initial resistances by multiplying the final resistance of the idle unit by the ratio of initial resistance of the loaded unit to the idle unit.

RATING OF OIL CIRCUIT BREAKERS WITH REFERENCE TO RUPTURING CAPACITY

BY

GEORGE A. BURNHAM

Presented under the auspices of the

Standards Committee

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RATING OF OIL CIRCUIT BREAKERS WITH REFERENCE TO RUPTURING CAPACITY

BY G. A. BURNHAM

Abstract of Paper

The paper advocates a universal method of rating oil circuit breakers which will be devoid of as many variables as possible.

Rating circuit breakers with reference to the aggregate full load of all synchronous apparatus alone is not sufficient to guide in the selection of the proper circuit breaker, as the location of the switching equipment and interposed lines is of equal importance.

If rupturing capacity were rated as " maximum instantaneous," meaning by " instantaneous " the elimination of time limit relays in tripping, it would eliminate all rating in reference to non-automatic, cell mounted, pipe frame, time-limit tripping, etc., and be confined entirely to the switch itself.

The author suggests that all circuit breaking devices be rated with reference to the rupturing capacity on their instantaneous action.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26-28, 1913.

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RATING OF OIL CIRCUIT BREAKERS WITH REFERENCE TO RUPTURING CAPACITY

BY GEORGE A. BURNHAM

There are several ways of rating the rupturing capacity of oil circuit breakers in use at the present time, and when comparing this class of apparatus of different manufacturers considerable explanation and detail are involved. For example, one company will rate the circuit breaker in " ultimate rupturing capacity;" another will specify that the circuit breaker is suitable for use on a circuit of certain characteristics or base the rupturing capacity on the aggregate full-load capacity of all synchronous apparatus.

The rating of oil circuit breakers with reference to rupturing capacity is an important matter and deserves the careful consideration of the Standards Committee.

The purchaser or user of this class of apparatus is interested in how much energy or kilovolt-amperes a particular circuit breaker will safely interrupt. The answer at the best is only an estimate based on familiarity with design, tests and actual service. I believe that most engineers and designers will agree that the proper selection of a circuit breaker with reference to rupturing capacity depends as much on the characteristics of generator, transmission line and translating devices as on the design of the circuit breaker itself. The designer has fixed the characteristic of the circuit breaker, but, on the other hand, has no control over the characteristic of the distribution system, and the characteristics are vastly different in transmission systems of the same kilovolt-ampere capacity.

Rating circuit breakers with reference to the aggregate full-load rating of all synchronous apparatus alone is not sufficient to guide in the selecting of the proper circuit breaker, as the location of the switching equipment, the interposed lines and apparatus are of equal importance.

It appears to the writer that the most definite and clear way of rating oil circuit breakers is to give the maximum "instantaneous" rupturing capacity, meaning by "instantaneous" the elimination of time-limit relays in tripping. This gives the engineer something definite and one can then judge whether or not the circuit breaker is suited for the particular requirements and the engineer of the distribution system or central station is in a better position to judge, as a general rule, than the designer, unless many details involving the characteristics of the system are first considered.

If rupturing capacity were rated as "maximum instantaneous" this would eliminate all ratings in reference to non-automatic, cell mounted, pipe-frame mounting, time-limit tripping, limitations as to reactance, etc., and be confined entirely to the switch itself, which after all is the important factor.

It is fairly well settled that, other things being equal, the rupturing capacity of an oil circuit breaker depends on the head of oil over the break at the starting of the arc, the amount of space above the oil for gas expansion, the shape and strength of the oil tank and its fastenings, and, to some extent, the length and rapidity of contact movement.

An automatic circuit breaker with its tripping features removed becomes a non-automatic circuit breaker, but has its rupturing capacity been altered? Does the application of the time-limit relay or cell construction actually increase the rupturing capacity, or does the introduction of reactance affect the circuit breaker itself? I think most engineers will agree that these factors do not actually affect the rupturing capacity of the switch but change only the character or value of the short-circuit current and at the instant of break tend to limit the kilovolt-amperes of the circuit to that of the circuit breaker or switch controlling it.

In view of these conditions, I would suggest for the consideration of the Standards Committee that all oil circuit-breaking devices be rated with reference to rupturing capacity on their "instantaneous action."

STRAY LOSS IN DIRECT-CURRENT COMMUTATING MACHINES

BY

H. F. T. ERBEN and H. S. PAGE

Presented under the auspices of the

Standards Committee

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STRAY LOSS IN DIRECT-CURRENT COMMUTATING MACHINES.

BY H. F. T. ERBEN AND H. S. PAGE

ABSTRACT OF PAPER

With an ultimate view to selecting such multiplying factors as will permit of the stray loss values in direct-current apparatus being estimated without resorting to actual test, this paper presents:

First. A brief description of the two elements comprising stray loss.

Second. Methods of testing for stray loss with a short discussion as to the comparative accuracy of each.

Third. Results of tests. The principal data are given in the form of curves showing the magnitude of stray loss at various loads on different machines. In connection with these results tentative suggestions are made as to possible multiplying factors.

The paper is incomplete inasmuch as enough reliable data were not available at the time of writing to draw definite conclusions. Supplementary data will be presented at the Midwinter Convention.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26-28, 1913.

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STRAY LOSS IN DIRECT-CURRENT COMMUTATING MACHINES

BY H. F. T. ERBEN AND H. S. PAGE

During the past two years there has been considerable discussion on the subject of load loss and many misunderstandings have arisen as to its nature and magnitude. To one not familiar with the accepted definition of the term, load loss might imply all of the losses occurring in a machine other than the no-load losses. In order to more clearly designate the subject under discussion the term defined in Section 114 of the Standardization Rules of the A. I. E. E. will be referred to in this paper as " stray loss " instead of " load loss."

In direct-current commutating machines stray loss may be divided into two elements: first, "commutation loss," consisting of such losses as arise from the improper reversal of current in the coils undergoing commutation, and second, " Loss due to flux distortion," resulting from the action of armature flux on main field flux.

Perfect commutation demands that the current in the coils be eversed in such a manner that it falls from a positive maximum to zero and continuing rises to a negative maximum uniformly as successive segments pass under the brush, and the magnitude of commutation loss depends upon the extent of divergence from this ideal condition. This latter condition is only obtained in cases where the coils undergoing commutation are passing through such a flux that an e.m.f. is generated in them whose instantaneous values are always equal to and opposite in direction to their own self-induction. Such a condition is most closely obtained in the modern commutating pole machines and in consequence the so-called commutation loss can be neglected. In machines of the non-commutating pole type where it is most difficult to obtain the correct commutating flux it is obvious that commutation loss may be of considerable magnitude, as frequently the current is not properly reversed during commutation. Even if the correct commutating flux is obtained for a a given load on such a machine it does not vary in such proportion to the current as to be correct for other loads. Non-commutating pole machines will, therefore, have one element of teh stray loss which is at a maximum at some fixed load but which will increase very rapidly at different loads.

A fair example of flux distortion is shown in Fig. 1. The symmetrical curve shown in solid line represents the flux distribution at no-load as obtained by the oscillograph. The corresponding broken line curve shows flux distribution at full load. It will be seen readily that with the iron worked through an entirely different cycle at full load than at no-load the hysteresis and eddy current losses will be altered. The maximum flux density in the teeth at no load represented by *O A* is raised 30 per cent to 40 per cent as represented by *O B*, thereby increasing the hysteresis loss and causing additional leakage through the slots with a resultant increase in eddy current loss in the copper.

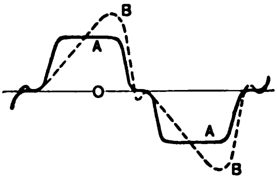

FIG. 1

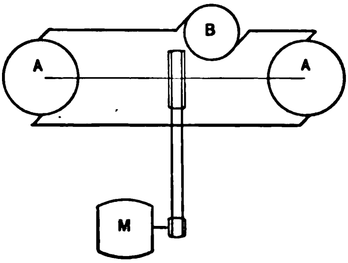

FIG. 2

In order to make efficiency tests taking stray losses into account it is necessary to load the machine to its full capacity, carefully observing either input and output or if two duplicate machines are at hand the total losses may be observed directly by the following method. In Fig. 2 the machines under test have the fields separately excited. At zero load no power is supplied from *B*, and *M* supplies power for all the losses except excitation. As load is applied, *B* furnishes power to circulate the armature current, the counter e.m.f. of machines *A*-*A* being kept alike, and *M* supplies additional power to compensate for the stray loss, thus allowing both machines to be fully loaded. Instruments indicating the losses are entirely independent of those measuring the load, consequently losses can be observed with a minimum error.

This paper will present data showing the magnitude of stray loss occurring in various types of " direct-current machines " and " synchronous converters," and from these data it will probably be possible to derive approximately correct formulas for general use in determining this loss. From facts later presented it will be seen that the actual value is such that quite an error in its estimation is permissible.

Input-output tests for efficiency are very expensive and frequently give inconsistent results. Errors of observation directly affect the determination of efficiency by this method and as an example of the possibilities of error the following table is given, showing results on 37 motors tested by the brake method.

H.p. output		H.p. stray loss	
2.01	+	0.0080	
2.03	—	0.0264	
3.1	—	0.0403	
3.1	+	0.034	
2.99	+	0.0508	
3.00	—	0.117	
4.97	+	0.0249	
4.93	+	0.045	
4.94	+	0.1475	
4.95	+	0.0638	
7.7	—	0.0231	
7.72	—	0.0077	
7.4	+	0.0074	
7.4	+	0.0444	
10.08	+	0.0201	
10.23	+	0.113	
9.62	—	0.279	
9.62	—	0.192	
14.9	+	0.313	
15	—	0.166	
15.15	+	0.273	
15.07	—	0.181	
20.5	—	0.0615	
20.5	—	0.1025	
2.00	+	0.084	
1.99	+	0.0139	
3.05	+	0.0061	
2.95	—	0.0678	
4.92	—	0.0541	
4.84	—	0.0921	
7.67	+	0.0077	
7.4	—	0.126	
10.06	—	0.040	
9.82	—	0.167	
14.96	—	0.06	
15.12	+	0.0605	
20.05	+	0.0802	
Total 311.75		3.6689	Total +
		1.8047	Total —
		1.8642	Net total +
			= 0.6 %

The resultant efficiencies were compared with efficiency figures obtained by the segregated loss method and the difference in each case considered as stray loss. The instruments were calibrated just before tests were made and all observations carefully checked. Many of the stray loss values appear as negative and in spite of the care taken to have correct observations made the results indicate a probable error greater than the stray loss itself. In these thirty-seven motors, ranging in capacity from 2 h.p. to 20 h.p., the total net stray loss shown was 1.86 h.p. for a total capacity of 312 h.p., giving a stray loss of 0.6 per cent. Inconsistencies which appear in these figures show that the results are of value only as an indication of the average stray loss and cannot be taken as correct for any one machine. This table is not given as an example of the most accurate results obtainable but rather as an example of results which will be obtained unless what might be termed "laboratory methods" are resorted to.

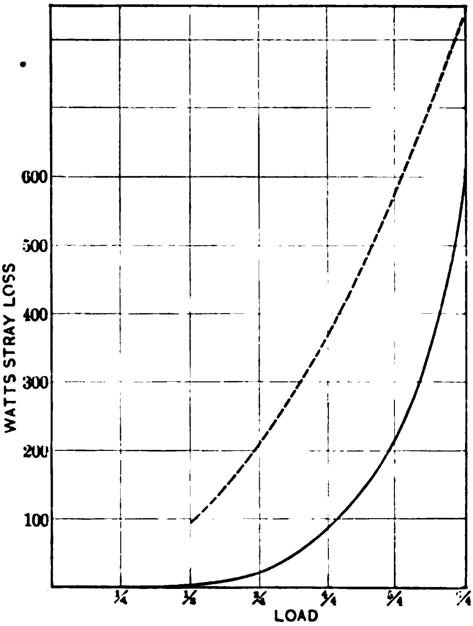

FIG. 3—FOUR-POLE, 20-KW.,1000-REV. PER MIN. GENERATOR.
I^2R armature 1060 watts. Iron and eddy current loss 360 watts

Stray loss values on five machines tested by the method described in connection with Fig. 2 are shown in Figs. 3 to 8 inclusive. In these tests the utmost care was taken in every detail, the losses were observed directly and the results are much more reliable than tabulated results given for the 37 small motors. The 150-kw. and 400-kw. generators, also the 500-kw. converter, were not fitted with commutating poles, consequently they show a stray loss at no-load due to the initial brush shift.

I^2R loss in the armature copper and iron plus eddy current loss as determined at no-load are given in each case.

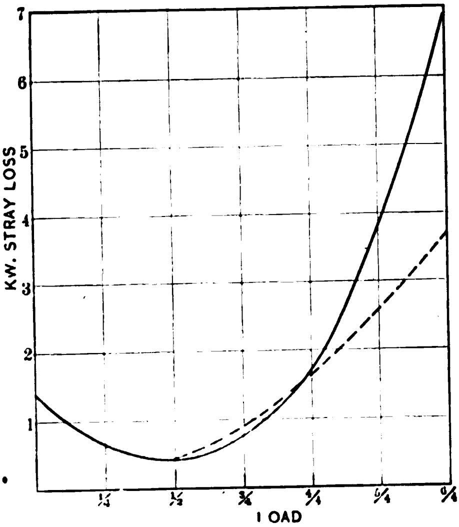

FIG. 4—SIX-POLE, 150-KW., 225-REV. PER MIN. GENERATOR.
I^2R armature 4700 watts. Iron and eddy current loss 1600 watts

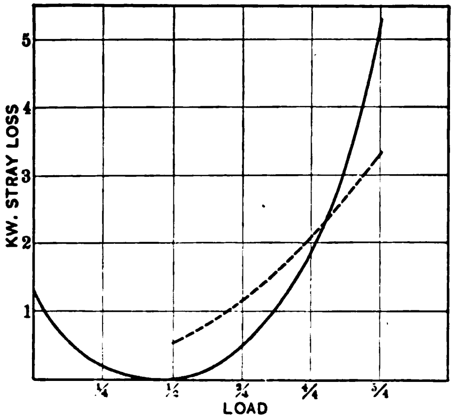

FIG. 5—FOUR-POLE, 500-KW., 750-REV. PER MIN., SYNCHRONOUS CONVERTER RUN AS 300-KW. GENERATOR.
I^2R armature, 3750 watts. Iron and eddy current loss 4400 watts.

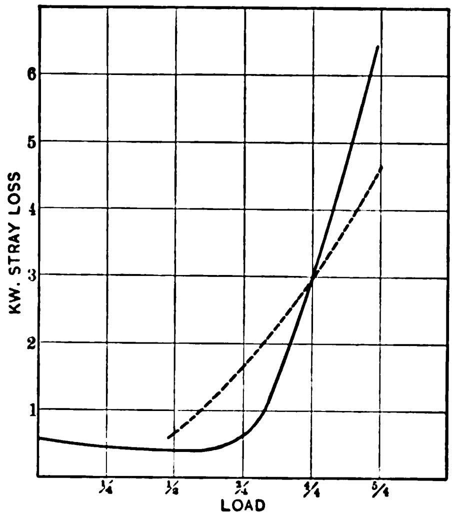

FIG. 6—EIGHT-POLE, 400-KW., 240-REV. PER MIN. GENERATOR
I^2R armature 7680 watts. Iron and eddy current loss 3720 watts

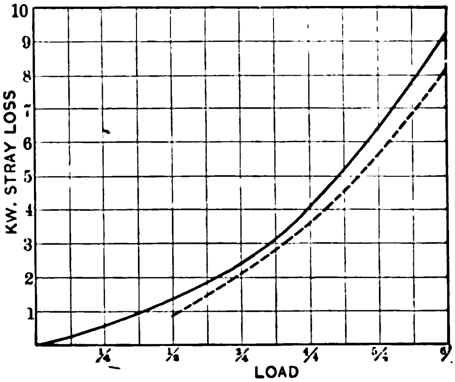

FIG. 7—FOUR-POLE, 500-KW., 720-REV. PER MIN. GENERATOR
I^2R armature 6400 watts. Iron and eddy current loss 7400 watts

Dotted curves shown in Figs. 3 to 8 are based on the assumption that stray losses at normal load are equal to 26 per cent of the no-load iron loss plus full load armature copper loss and vary as the square of the load. This factor of 26 per cent, chosen to suit the average stray loss of the four larger machines, is evidently too high a multiplying factor for the 20-kw. generator.

Fig. 8 shows the curves of Figs. 3 to 7 combined with the percentage stray loss in each plotted against load. The two dotted curves show stray loss values varying as the cube and square of the load, 0.7 per cent stray loss being arbitrarily chosen at the normal load point.

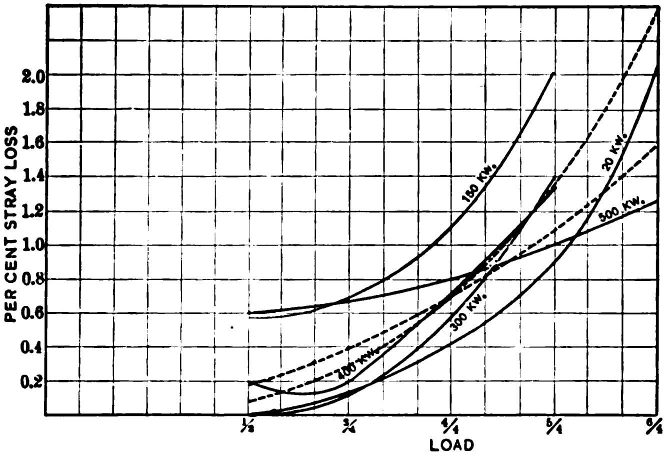

FIG. 8

In this paper no definite conclusions are drawn as to a suitable multiplying factor for indicating stray loss. Results of further tests made on different apparatus together with a recommendation as to suitable multiplying factors will be presented at the Midwinter Convention of the Institute.

REGULATION OF DEFINITE POLE ALTERNATORS

BY

SOREN H. MORTENSEN

Presented under the auspices of the

Standards Committee

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REGULATION OF DEFINITE POLE ALTERNATORS

BY SOREN H. MORTENSEN

ABSTRACT OF PAPER

Since the method recommended by the A. I. E. E. for obtaining regulation of alternators from no-load saturation, short-circuit curve and armature resistance in most cases gives incorrect results, another method called the "triangle method" is suggested. This method requires the same tests as the A. I. E. E. method, and drives the regulation by means of the Kapp diagram from an estimated full load zero power factor saturation curve, which in turn is determined with the aid of Potier's triangle. Potier's triangle is derived from no-load saturation and short-circuit curve by means of a simplified equation for armature reaction.

A series of tables follows, in which regulations obtained by triangle and A. I. E. E. methods are compared with results obtained from actual test.

The tables prove that the triangle method is the more accurate. Hence the suggestion to supersede the present A. I. E. E. method by the triangle method.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26–28, 1913.

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(*Subject to final revision for the Transactions.*)

REGULATION OF DEFINITE POLE ALTERNATORS

BY SOREN H. MORTENSEN

The question of determining regulation of synchronous generators from shop tests has been treated by various authors in the past.* In most cases, it is hardly practicable to determine regulation under actual load conditions. As an alternative, the American Institute of Electrical Engineers has recommended a method of obtaining regulation from no-load saturation, short circuit characteristics, and armature resistance. However, this method, as has been proven, gives in most cases incorrect results.

The object of this paper is to supply data collected from tests on various machines showing that, with the same tests as needed for the A. I. E. E. method, and very little more work, approximately correct regulation results can be obtained by what may be called the "triangle method." In it, regulation is derived by means of the Kapp diagram from a full load, zero power factor saturation curve, which in turn has been derived from a no-load saturation and short-circuit curve with the aid of Potier's triangle.

The tables given further on show results obtained by the triangle and the A. I. E. E. methods, as compared with regulation derived from actual full load, zero power factor saturation curve.

To determine Potier's triangle for a machine, when its no-load saturation and short-circuit curves are known, it is only necessary to calculate the magnetomotive force of direct armature reaction, that is, the back ampere-turns per pole. Armature

---

*B. A. Behrend	A. I. E. E. Transactions	Vol. 21—1903.
Hobart & Punga	" "	" 32—1904.
B. T. McCormick	" "	" 23—1904.

transverse reaction is practically zero when a machine is run on short circuit. The armature reactance can be found directly from the no-load saturation and short-circuit curves as shown in Fig. 1 ($I\,x$ component.)

The generally accepted equation for magnetomotive force of direct armature reaction under purely inductive load, zero power factor, may be expressed as follows:

$$A\,T = 0.9 \times K_s \times K_m \times K_d \times \sin\phi \times N \times I \times T \quad \textbf{(1)}$$

$A\,T$ = Reaction (back ampere turns) expressed in ampere turns.

K_s = Factor for fractional stator coil pitch same as for e.m.f calculations.

K_d = Distribution factor taking into account number of slots per pole per phase, same as used for e.m.f. calculations.

*K_m = Coefficient of direct reaction.

Sin ϕ = Factor taking into account that displacement between e.m.f. and short-circuit current is not quite 90 deg. due to short-circuit stray losses.

N = Number of phases.

I = Armature current per phase.

T = Number slots per pole per phase

$$\times \frac{\text{No. conductors per slot}}{2 \times \text{No. circuits of arm. wdg.}}$$

For practical purposes, we may substitute mean values for several of the factors found in equation (**1**) without committing any appreciable error, as variation of these factors is small, as shown below.

The value of sin ϕ was determined for a number of machines from short-circuit stray loss curve, and it was found to vary between 0.97 and 0.99.

$$K_m \text{ is a function of the ratio } \frac{\text{pole arc}}{\text{pole pitch}} \text{ which for}$$

machines of modern design generally will fall between 54 per cent and 75 per cent. For these values K_m would vary between 0.885 and 0.78 if the pole face is shaped concentric with armature bore. As the pole face is frequently chamfered, these values have to be modified. From tests on numerous machines of different design, it has been found that a mean value of 0.79 for K_m gives consistent results. As the variation in the value of the distribution factor K_d for 3 and two-phase machines is rather small, a mean value of $K_d = 0.96$ for three-phase machines, and $K_d = 0.92$ for two-phase machines may be taken.

---

*For derivation of K_m see Kapp's " Dynamo Machines "—1904.

Single-phase machines are often built on two- or three-phase armature punchings, by leaving certain slots empty. K_d thus varies over a much wider range than is the case for two-phase and three-phase machines, and hence no mean value has been

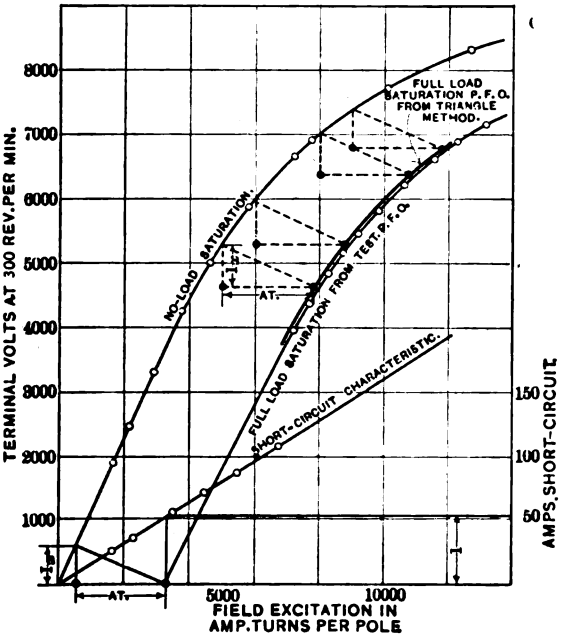

FIG. 1

assumed. By choosing average values as indicated above, we thus obtain the following simple equation for back ampere-turns:

$$A\,T = 2\,I\,T \text{ for three-phase machines} \qquad (2)$$

$$A\,T = 1.3\,I\,T \text{ for two-phase machines} \qquad (3)$$

$$A\,T = 0.72\,K_d\,I\,T \text{ for single-phase machines} \qquad (4)$$

Using the above equations for determining Potier's triangle, the results, shown in tables, were worked up from tests. The full-load saturation, zero power factor curve was determined by sliding triangle along the no-load saturation curve as shown in Fig. 1.

Regulation for power factors given in Tables A, B and C was then derived by means of a Kapp diagram.

For machines with high pole densities and a large field leakage, the triangle method will give more favorable regulation results than will actual tests, since in deriving the load saturation curve from no-load saturation and short-circuit curve, no consideration is taken of increased field leakage due to load conditions.*

Figs. 2 and 3 show curves from machines with high magnetic densities. In Fig. 2, saturation is in armature iron, and here curves from triangle method and test check each other closely. Fig. 3 is from a machine with an unusually large pole density

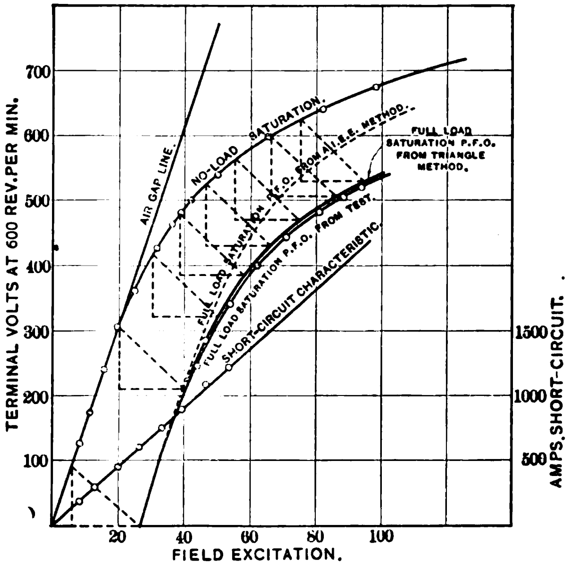

FIG. 2

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*Corrections for load field leakage may be made if, before applying triangle method, the no-load saturation curve is replotted for a field leakage of σ' instead of σ if

σ' = field leakage flux for full load zero power factor saturation curve.

σ = field leakage flux for no-load saturation curve.

And further

K = constant depending on pole pitch and shape

$A\ T$ = armature back ampere turns from equation (1)

Then $\sigma = K \times$ ampere-turns for (air gap + armature iron)

and $\sigma' = K \times$ amp.-turns for (air gap + arm. iron + $A\ T$)

TABLE A—FOR THREE-PHASE MACHINES

Rating			No. slots per pole per phase	Pole arc pole pitch	Regulation					
					By A. I. E. E. method		From full load sat. curve		By triangle method	
Kw.	Volts	Speed r.p.m.			P. F. 1	P. F.0.8	P.F. 1	P. F.0.8	P. F. 1	P. F. 0. 8
200	2300	1800	4	0.54	11.	23.	11.2	25.	11.2	25.2
600	6600	300	3	0.62	4.3	15.	6.5	17.5	6.2	17.1
2800	2300	720	3	0.685	9.	21.8	10.	24.	9.7	23.6
600	2300	150	1	0.60	7.1	17.4	8.5	24.2	8.3	23.4
250	480	120	2	0.72	8.3	18.6	11.4	27.	10.3	25.5
525	2200	500	4	0.54	16.4	31.	18.2	33.6	17.6	33.
200	2300	200	1	0.61	5.1	19.	8.3	25.5	8.2	24.6
200	2300	150	2	0.72	11.1	25.	13.5	31.2	12.5	30.
500	11000	100	1	0.66	9.2	21.8	12.8	28.2	12.2	27.8
1000	2300	82	1	0.68	6.4	17.2	7.9	23.5	7.6	23.
1750	6600	100	2	0.71	6.	18.2	11.	22.	9.9	21.1
1000	2400	180	3	0.66	9.1	21.	10.6	26.2	10.2	25.2
225	2200	900	2	0.55	10.	22.3	11.8	24.2	11.7	24.1
625	2300	300	2	0.702	3.7	11.5	4.3	16.6	4.4	16.7

TABLE B—FOR TWO-PHASE MACHINES

Rating			No. slots per pole per phase	Pole arc pole pitch	Regulation					
					By A. I. E. E. method		From full load sat. curve		By triangle method	
Kw.	Volts	Speed r.p.m.			P. F. 1	P. F.0.85	P.F. 1	P.F. 0.85	P. F. 1	P F. 0.85
500	2300	120	2	0.597	4.5	15.6	8.5	19.5	8.	19.5
250	1100	120	2	0.57	5.	17.	5.7	20.5	5.9	20.6
420	125	240	2	0.64	16	33.	20	38.	20	38.
125	440	277	3	0.68	8.5	21.5	9.1	24.8	8.7	23.8
1000	2200	500	6	0.56	5.	14.8	5.4	16.5	6.	17.3
700	2300	120	2	0.598	6¼	13.9	8.7	20.4	8.6	20.3

TABLE C—FOR SINGLE-PHASE MACHINES

Rating			No. slots per pole per phase	Pole arc pole pitch	Regulation					
					By A. I. E. E. method		From full load sat. curve		By triangle method	
Kw.	Volts	Speed r.p.m.			P. F. 1	P. F.0.85	P.F. 1	P.F. 0.85	P. F. 1	P.F. 0.85
			empty							
75	440	250	6—2	0.66	2.7	12.2	5.4	17.9	5.9	18.2
90	2300	900	6—2	0.55	8.8	20.	11.	28.	10.6	27.3
260	2300	150	3—1	0.60	3.	10.4	6.	18.	6.	17.9
160	2200	200	3—1	0.60	11.7	24.	16.	30.	15.	28.9
65	2200	277	3—1	0.62	9.1	20.2	14.	31.5	14.	31.

and a large field leakage. Here, field leakage due to ampere-turns compensating armature reaction causes the load saturation curve to lean over more than indicated by the triangle method. The latter, however, is more accurate than the A. I. E. E. method.

In general, it may be said that results show that the triangle method gives regulation considerably nearer the actual than does the A. I. E. E. method. Moreover, the triangle method is so simple as to be easily applied. Data for use in equations (**2**), (**3**) and (**4**) can be taken directly from a winding specification. No-load saturation, short-circuit curve, and armature resistance are

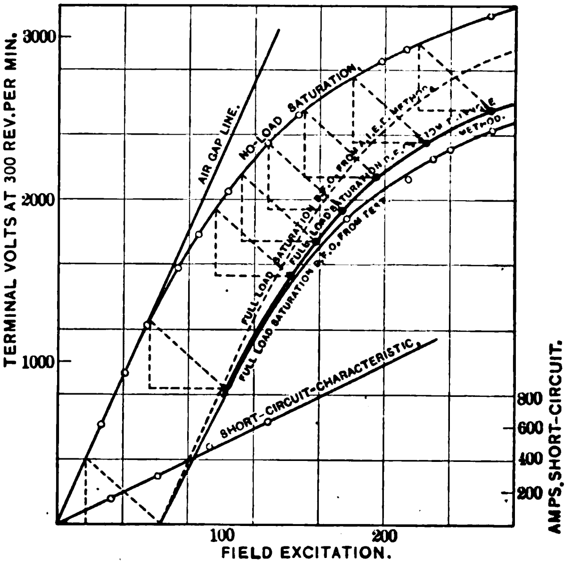

FIG. 3

always available, and the graphical operation involved to get regulation at any power factor is as simple as the present A. I. E.E method. The Kapp diagram can be simplified if the influence of ohmic resistance is neglected. This can be done in most cases without impairing the accuracy of the results.

Thus, it would seem that the triangle method has proved itself sufficiently accurate and also simple enough to be practicable; it might therefore be considered as a fitting substitute for the present A. I. E. E. method.

THE SPHERE SPARK GAP

BY

S. W. FARNSWORTH and C. L. FORTESCUE

Presented under the auspices of the

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THE SPHERE SPARK GAP

BY S. W. FARNSWORTH AND C. L. FORTESCUE

ABSTRACT OF PAPER

The limitations of the present needle point spark gap are discussed and the use of a spark gap having two equal spheres is proposed.

The space required by a vertical sphere gap having the lower sphere grounded is very much less than that required by a needle point gap for the same voltage range.

Corona and resultant inconsistencies are prevented if the spheres are used over a separation not greater than their diameter. This leads to large spheres for high voltages.

Sphere gaps have proved satisfactory in commercial testing because they are reliable, more convenient, require less floor space, and are portable.

Spheres of 25 cm., 37½ cm., and 50 cm. diameter covering ranges of approximately 50,000 to 275,000; 50,000 to 412,500 and 50,000 to 550,000 volts effective values, respectively, are proposed as standards.

A few features are suggested to be incorporated in the Standardization Rules.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26-28, 1913.

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(*Subject to final revision for the Transactions.*)

THE SPHERE SPARK GAP

BY S. W. FARNSWORTH AND C. L. FORTESCUE

For many years the spark gap method of measuring high voltages has been universally used. No indicating meter satisfactory for commercial uses has yet been developed which will measure the maximum voltage as will the spark gap. Numerous investigators have made calibration curves for the spark gap using needle point electrodes under widely varying conditions. The results obtained under like conditions have checked fairly well over a range of voltage up to about 100,000. Above this voltage it has been very hard to duplicate conditions near enough for different investigators to obtain results which are in agreement.

Since voltages of 100,000 and above have come into use requiring test voltages of 200,000 and above, the need for some more reliable means of measuring the voltage has been greatly desired. While investigating the dielectric strength of air the authors had occasion to use a sphere gap and were so favorably impressed by the consistent results obtained that the idea soon presented itself of using such a gap to replace the needle point gap.

Those who are daily handling high voltages know well the inconsistency of the needle point gap and others should be convinced of it by the great number of different empirical equations derived by different investigators showing relation between distance of separation and breakdown voltage. Besides giving inconsistent results the needle point spark gap is cumbersome and requires a great deal of space. Section 245 of the A. I. E. E. Standardization Rules specifies the following:

" The spark points should consist of new sewing needles supported axially at the ends of linear conductors which are at least twice the length of the gap. There should be no extraneous body near the gap within a radius of twice its length." For 300,000 volts, the highest voltage given in the A. I. E. E. table, the sparking distance between needle points is 77.4 cm. (30.50 in.). If constructed according to the rule given above, the structure will have the dimensions given in Fig. 1. It is seen that a space 6.19 meters (20.33 ft.) long by 2.9 meters (11.83 ft.) wide and high is required. Three-hundred thousand volts is by no means the highest voltage manufacturers are being called upon to measure and with increased voltage the problem becomes more difficult to solve satisfactorily. Compare the space required for the needle point gap with the space of 1.22 meters by 1.52 meters by 2.42 meters high required for a 37.5-cm. sphere gap having one end grounded and having a range of 412,500 volts, effective value. Fig. 2 gives the dimensions of such a gap as constructed and used.

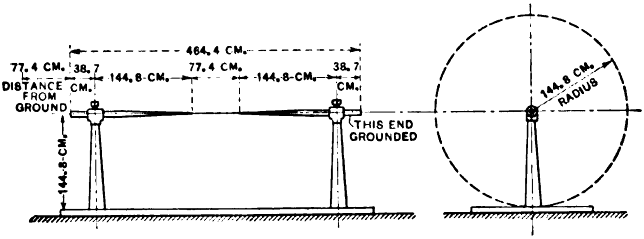

FIG. 1

A sphere gap becomes inconsistent as soon as corona forms preceding break-down voltage. This only happens when the spheres are separated a distance greater than their diameter. When separated less than their diameter a progressive break-down follows immediately upon the break-down of the film of air at the surface of the sphere.* Consequently a pair of spheres should only be used for measuring voltages up to that necessary to break down the air between them when separated a distance approximately equal to their diameter. With one end grounded, 25-cm., 37.5-cm. and 50-cm. spheres have ranges from 50,000 up to approximately 275,000, 412,500, and 550,000 volts, effective values, respectively. Other sizes have ranges in proportion.

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*Alexander Russell and others have given mathematical proof as to why this is so. See " The Dielectric Strength of Air." *The Philosophical Magazine and Journal of Science*, Volume 11, Sixth Series, page 237.

With middle point grounded, 25-cm., 37.5-cm. and 50-cm. spheres have ranges up to approximately 330,000, 440,000 and 650,000 volts, respectively. Other sizes have ranges in proportion.

Fig. 2 gives the dimensions for the 25-cm., 37.5-cm., and 50-cm. gaps. Being constructed vertically they use a very small floor space as compared with equivalent horizontal needle point gaps. The top sphere is stationary but slightly adjustable in height so as to just make contact with the lower sphere when it is set for zero separation. The lower sphere is mounted on a piece of brass tubing which carries a threaded bushing on its lower end. This bushing works on a carefully threaded rod having a pitch of two per centimeter. The bushing being graduated to fiftieths on its circumference, separation may be measured to the nearest 1/100 cm.

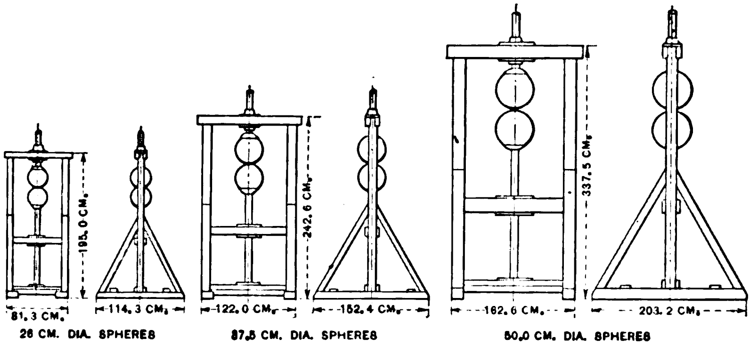


FIG. 2

directly. Thus, there is a micrometer adjustment provided. Being made of large parts the whole arrangement is mechanically strong and the spheres are kept in constant alignment. Being mounted on large wheels the spark gap sets are very portable and may also be picked up by a crane without risk of damage.

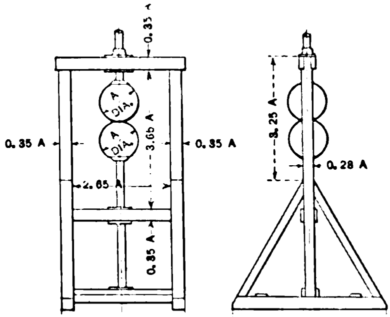
The first pair of spheres 25.4 cm. (10 in.) diameter were made up early in 1910 and immediately became so popular on the testing floor because of their consistency and convenience that the use of the needle point gap was entirely abandoned. These original spheres are still in use and show no sign of surface deterioration due to the arc. Various resistances have been used in series with the gap to limit the current upon break-down. A value of one ohm per volt for the maximum voltage for which the set is to be used has been found to give entire satisfaction and the resistance may be of any convenient form. The proximity of neighboring bodies has been found to have little effect on the break-down voltage of a given gap. The effects of atmospheric pressure and humidity have also had only a negligible effect on the break-down voltage.

The sphere gap thus offers a means of measuring high voltages which has the following advantages over the needle point gap:

More consistent, the break down voltage being affected only to a negligible degree by widely varying conditions of atmospheric pressure, humidity, proximity of neighboring bodies, etc.

More convenient, because the terminals do not have to be renewed and a micrometer adjustment provides ready means of setting accurately for any separation without adjusting for zero.

Requires much less floor space.



NOTE:-
A VARIATION OF 1 CM. IN THICKNESS AND WIDTH OF WOODEN PARTS IS PERMISSIBLE.

FIG. 3

Is more portable because of its better mechanical construction and smaller size.

In view of the above advantages which have been found to exist during nearly three years' use in commercial testing, the authors feel that the sphere spark gap may be well considered as a standard to replace the needle gap standard.

It is suggested that the following features be incorporated in the Standardization Rules covering the measurement of high voltages:

1. Either one end or the middle point of the high-tension winding should be grounded. In case the middle point is grounded, the high-tension voltage from one terminal to ground may be measured by the spark gap and total voltage taken as twice this value.

2. The spark gap shall consist of two accurately machined spheres supported vertically by a wooden frame work having its dimensions proportional to the diameter of the sphere used, as shown in Fig. 3.

3. The 25-cm., 37.5-cm. and 50-cm. spheres shall be standard sizes covering voltage ranges of 50,000 to 275,000, 50,000 to 412,500 and 50,000 to 550,000 volts, effective values, respectively. The lower sphere shall always be grounded.

For voltages below 50,000 a smaller size of sphere may be used. The authors are not at present in a position to recommend a definite size. It is suggested that the calibration of the standard sizes should be done under the direction of the Standards Committee.

STRAY LOSSES IN TRANSFORMERS

BY

C FORTESCUE and W. M. McCONAHEY

Presented under the auspices of the

Standards Committee

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STRAY LOSSES ON TRANSFORMERS

BY C. FORTESCUE AND W. M. MCCONAHEY

ABSTRACT OF PAPER

The object of this paper is to obtain a convenient method of evaluating the actual losses in the copper of a transformer and in figuring the regulation.

The effects of various factors on the copper loss of transformers are discussed. It is pointed out that they are, as a rule, negligible in well designed transformers.

It is shown theoretically that the copper loss and regulation of a mutual inductance may be derived from its short circuit loss and impedance voltage. The transformer differs from the mutual inductance, due to the fact that the primary and secondary inductances are functions of the induction in the iron. It might be inferred therefore that the short circuit losses, as obtained in the ordinary way, might differ from the equivalent quantities obtained under full load condition. The equation derived in Section 2 furnishes a method of testing to obtain this equivalent short circuit loss under full load conditions. To ascertain if the values of short circuit loss and impedance, obtained in this way, differ from those obtained in the ordinary way, tests were made by both methods yielding results which, after proper corrections were made, checked very closely. Results of tests are tabulated. Practical formulas for figuring copper loss and regulation are given. Recommendations are made as to tests and formulas to be used for obtaining true copper loss and regulation.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26-28, 1913.

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(Subject to final revision for the Transactions.)

STRAY LOSSES IN TRANSFORMERS

BY C. FORTESCUE AND W. M. McCONAHEY

(1) INTRODUCTION

The object of this paper is to obtain a convenient method of evaluating the actual losses in the copper of a transformer under operating conditions, and of figuring the regulation.

The losses in the copper of a transformer are influenced by several conditions, namely,

a. Frequency and wave form
b. Dissymmetry of winding
c. Permeability of iron
d. Temperature.

a. The portion of the losses in the copper that depends on frequency is included in what is termed " eddy-current loss in the copper," analagous to " skin effect " in line conductors, and is practically eliminated in careful designs. Higher harmonics in the wave form of impressed e.m.f. have also some effect on these losses as would naturally be expected since they are dependent upon frequency.

b. The losses due to dissymmetry of winding are confined to transformers with parallel connections when the different circuits forming the parallel connected secondary are not similarly disposed with regard to the primary circuit and one another. These losses are independent of frequency and are of little importance since they will be negligibly small in good designs:

c. The losses in the copper may be affected by the permeability of the iron. If eddy-current losses are present these will be affected by any change in the leakage induction due to a change of permeability. The permeability will affect the value of the exciting current and thereby the copper loss under load. These effects are, however, usually so small as to be negligible except in special cases.

d. Temperature will have the effect of increasing the true I^2R losses and decreasing the eddy-current losses. Where a transformer has large eddy-current losses its copper loss should be measured if possible at the temperature on which gurantees are based. A first approximation to the effect of temperature on eddy-current losses may be obtained by considering them directly proportional to the conductivity of the copper and correcting for temperature accordingly.

(2)THEORETICAL STUDY OF COPPER LOSSES IN TRANSFORMERS

The theory of the transformer depends on that of two mutually inductive circuits. A clear understanding of the actions that take place in transformers cannot be obtained without a careful study of the theory of such a pair of circuits. It must not be supposed, however, that a system of this kind can be made to represent a transformer exactly; on account of the peculiar characteristics of iron this is impossible. It furnishes, however, a model sufficiently close to be accurate enough for all practical purposes. The resistances and inductances of the two circuits will be influenced by frequency, temperature, etc. in the same way as the windings of a transformer. Results obtained mathematically for such a pair of circuits will apply with almost equal accuracy to transformers.

Let the resistance and inductance of the primary circuit be R_1 and L_1 and those of the secondary R_2 and L_2; let the mutual inductance be M and the resistance and self-inductance of the load on the secondary circuit be R_0 and L_0; let e_1, be the value of the impressed e.m.f. The differential equations of the two circuits are,

$$L_1 \frac{d\,i_1}{d\,t} + M \frac{d\,i_2}{d\,t} + R_1\,i_1 = e_1 \tag{1}$$

$$(L_2 + L_0) \frac{d\,i_2}{d\,t} + M \frac{d\,i_1}{d\,t} + (R_2 + R_0)\,i_2 = 0 \tag{2}$$

From (2) we have

$$i_2 = - \frac{M \dfrac{d}{d\,t}}{(R_2 + R_0) + (L_2 + L_0) \dfrac{d}{d\,t}}\, i_1 \tag{3}$$

Substituting this in (**1**)

$$\left(L_1 \frac{d}{d\,t} - \frac{M^2 \dfrac{d^2}{d\,t^2}}{(R_2 + R_0) + (L_2 + L_0)\dfrac{d}{d\,t}} + R_1 \right) i_1 = e_1$$

or

$$\left\{ R_1 - \frac{M^2 \dfrac{d^2}{d\,t^2}}{(R_2 + R_0)^2 - (L_2 + L_0)^2 \dfrac{d^2}{d\,t^2}} (R_2 + R_0) + \left(L_1 + \frac{M^2 \dfrac{d^2}{d\,t^2}}{(R_2 + R_0)^2 - (L_2 + L_0)^2 \dfrac{d^2}{d\,t^2}} (L_2 + L_0) \right) \frac{d}{d\,t} \right\} i_1 = e_1 \qquad (\mathbf{4})$$

If e_1 be a harmonic function of time it may be represented by the real part of the complex variable function

$$\Sigma \, \{ (a_n + j\, b_n)\, e^{j n p t} \}$$

The final or steady value of i_1 will then be the real part of the similar expression afforded by the particular integral of equation (**4**); or denoting the complex variable function representing in its real part the value of i_1 by $\check{I}_1$ we have equations (**5**) and (**6**).

$\check{E}_1$ represents the complex variable function the real terms of which give the instantaneous value of e_1 and $\hat{Z}_a$ represents the operation $R_a + j\,n\,p\,L_a$ on each successive term of the quantities $\check{I}_1$ and $\check{E}_1$, the value of n being the same as that in the index of the base of the Naperian logarithm contained in the term operated on. The values of R_a and L_a will be

$$R_a = R_1 + \frac{n^2 p^2 M^2}{(R_2 + R_0)^2 + n^2 p^2 (L_2 + L_0)^2} (R_2 + R_0) \qquad (\mathbf{7})$$

$$L_a = L_1 - \frac{n^2 p^2 M^2}{(R_2 + R_0)^2 + n^2 p^2 (L_2 + L_0)^2} (L_2 + L_0) \qquad (\mathbf{8})$$

$$\check{I}_1 = \Sigma \left\{ \frac{(a_n + j\,b_n)\,e^{j\,n\,p\,t}}{R_1 - \dfrac{M^2 \dfrac{d^2}{d\,t^2}}{(R_2 + R_0)^2 - (L_2 + L_0)^2 \dfrac{d^2}{d\,t^2}}\,(R_2 + R_0) + \left(L_1 + \dfrac{M^2 \dfrac{d^2}{d\,t^2}}{(R_2 + R_0)^2 - (L_2 + L_0)^2 \dfrac{d^2}{d\,t^2}}\,(L_2 + L_0) \right) \dfrac{d}{d\,t}} \right\}$$

$$= \Sigma \left\{ \frac{(a_n + j\,b_n)\,e^{j\,n\,p\,t}}{R_1 + j\,n\,p\,L_1) + \dfrac{n^2\,p^2\,M^2}{(R_2 + R_0)^2 + n^2\,p^2\,(L_2 + L_0)^2} \left\{ (R_2 + R_0) - j\,n\,p\,(L_2 + L_0) \right\}} \right\} \qquad (5)$$

$$= \frac{\check{E}_1}{\hat{Z}_a} \qquad (6)$$

This gives the effective resistance and inductance of the primary circuit with loaded secondary to the *n*th harmonic component of the impressed e.m.f

Using the same notation, equation **(3)** may be put into the form

$$\check{I}_2 = - \frac{j\, n\, p\, M}{(R_2 + R_0) + j\, n\, p\, (L_2 + L_0)} \check{I}_1 \tag{9}$$

If the load resistance and inductance be made zero we shall have the effective resistance of the system under short circuit, that is,

$$R_b = R_1 + \frac{n^2 p^2 M^2}{R_2^2 + n^2 p^2 L_2^2} R_2 \tag{10}$$

$$L_b = L_1 - \frac{n^2 p^2 M^2}{R_2^2 + n^2 p^2 L_2^2} L_2 \tag{11}$$

Similarly if the primary winding be short circuited and the current circulated through the secondary, the effective resistance and inductance will be

$$R_c = R_2 + \frac{n^2 p^2 M^2}{R_1^2 + n^2 p^2 L_1^2} R_1 \tag{12}$$

$$L_c = L_2 - \frac{n^2 p^2 M^2}{R_1^2 + n^2 p^2 L_1^2} L_1 \tag{13}$$

The secondary terminal e.m.f. under load is

$$\check{E}_2 = \check{I}_2 \hat{Z}_0 \tag{14}$$

The secondary e.m.f. at no load is

$$\check{E}_0 = - \frac{j\, n\, p\, M}{R_1 + j\, n\, p\, L_1} \check{E}_1 \tag{15}$$

by **(6)** this is

$$\check{E}_0 = - \frac{j\, n\, p\, M}{R_1 + j\, n\, p\, L_1} \check{I}_1 \hat{Z}_a$$

and by **(9)** this is

$$\overset{\vee}{E}_0 = \frac{(R_2 + R_0) + j\,n\,p\,(L_2 + L_0)}{R_1 + j\,n\,p\,L_1}\,\overset{\vee}{I}_2\,\hat{Z}_a \qquad \textbf{(16)}$$

from **(14)** and **(16)**.

$$\overset{\vee}{E}_0 - \overset{\vee}{E}_2 = \overset{\vee}{I}_2 \left\{ \frac{(R_2 + R_0) + j\,n\,p\,(L_2 + L_0)}{R_1 + j\,n\,p\,L_1}\,\hat{Z}_a - \hat{Z}_0 \right\}$$

or substituting for $\hat{Z}_a$ and $\hat{Z}_0$

$$\overset{\vee}{E}_0 - \overset{\vee}{E}_2 = \overset{\vee}{I}_2 \left\{ (R_2 + j\,n\,p\,L_2) + \frac{n^2\,p^2\,M^2}{R_1^2 + n^2\,p^2\,L_1^2}\,(R_1 - j\,n\,p\,L_1) \right\} \qquad \textbf{(17)}$$

This latter expression gives the basis on which to calculate the regulation of transformers. For air coils having mutual inductance it gives exactly the same effective resistance and inductance as obtained with short circuited primary and current circulated through the secondary. [See **(12)** and **(13)**]. With transformers where L_1 and L_2 are functions of the induction it gives the effective short circuit resistance and inductance under load conditions, and these may be slightly different from those obtained with short circuit.

From **(1)** we obtain another expression for $\overset{\vee}{I}_1$

$$\overset{\vee}{I}_1 = \frac{\overset{\vee}{E}_1}{R_1 + j\,n\,p\,L_1} - \frac{j\,n\,p\,M}{R_1 + j\,n\,p\,L_1}\,\overset{\vee}{I}_2 \qquad \textbf{(18)}$$

$$= \overset{\vee}{I}_m - \frac{j\,n\,p\,M}{R_1 + j\,n\,p\,L_1}\,\overset{\vee}{I}_2 \qquad \textbf{(19)}$$

The first term is the open circuit exciting current; the second term is the current obtained in the primary when it is short circuited and current I_2 is sent through the secondary winding. If $|I_m|_n|I_1|_n$ and $|I_2|_n$ denote the effective values of the nth term of the series representing each of the quantities $\overset{\vee}{I}_m$ $\overset{\vee}{I}_1$ and $\overset{\vee}{I}_2$ and if φ_n be the phase displacement between the nth harmonic of $\check{E}_1$ and $\check{I}_2$ we have from (**19**)

$$I_1^2 = \Sigma\ \{|I_1|_n^2\}$$

$$= I_m^2 + \Sigma \left\{ \frac{n^2 p^2 M^2}{R_1^2 + n^2 p^2 L_1^2} |I_2|_n^2 + 2 \frac{n\, p\, M}{\sqrt{R_1^2 + n^2 p^2 L_1^2}} |I_m|_n |I_2|_n \sin \varphi_n \right\} \qquad (\mathbf{20})$$

The true copper loss is

$$I_1^2 R_a - I_2^2 R_0 = I_1^2 R_1 + I_2^2 R_2$$

$$= I_2^2 R_2 + \Sigma \left\{ \frac{n^2 p^2 M^2}{R_1^2 + n^2 p^2 L_1^2} |I_2|^2_n R_1 \right\}$$

$$+ 2\, \Sigma \left\{ \frac{n\, p\, M}{\sqrt{R_1^2 + n^2 p^2 L_1^2}} |I_m|_n |I_2|_n R_1 \sin \varphi_n \right\} + I_m^2 R_1 \qquad (\mathbf{21})$$

The first two values on the right hand side of equation (**21**) is the copper loss as obtained from (**18**) which, as will be shown later, may be obtained by measurement. It will also be shown to be practically the same as the loss obtained under short circuit. The fourth term is constant for a given impressed e.m.f. and is included in the iron loss measurement. The third term is the correction to be made to the loss as obtained by (**17**) or the short circuit method to obtain the correct value of the copper loss. In practical application of this correction the quantity

$$\frac{n\, p\, M}{\sqrt{R_1^2 + n^2 p^2 L_1^2}}$$

may be taken to be equal to n_2/n_1 where n_1 and n_2 are the primary and secondary turns.

(3) Method of Measuring Impedance and Short Circuit Loss Under Load

It has been shown how the true copper loss in the case of two mutually inductive circuits may be obtained by a correction to be added to the copper loss obtained under short circuit. In transformers the old method of obtaining the short circuit loss has been subjected to criticism on the ground that the condition of the iron when the transformer is under load as regards permeability is very different from its condition when one winding is short circuited and full load current circulated through the other. Equation (**17**) furnishes us with a theoretical basis for obtaining the value of the short circuit losses with conditions of induction obtained under operation. As regards mutually inductive circuits in air the difference between the open circuit voltage of the secondary and the full load voltage as shown by (**17**) is the mathematical equivalent of the impedance voltage obtained with the primary short circuited and full load current circulated in the secondary winding. With transformers there is a difference between these two quantities due to the permeability being different at high and low induction. Thus for transformers (**17**) gives the short circuit impedance and short circuit loss with the same induction in the iron as that obtained under load, while (**12**) and (**13**) give the resistance and inductance obtained under short circuit when the induction is very low.

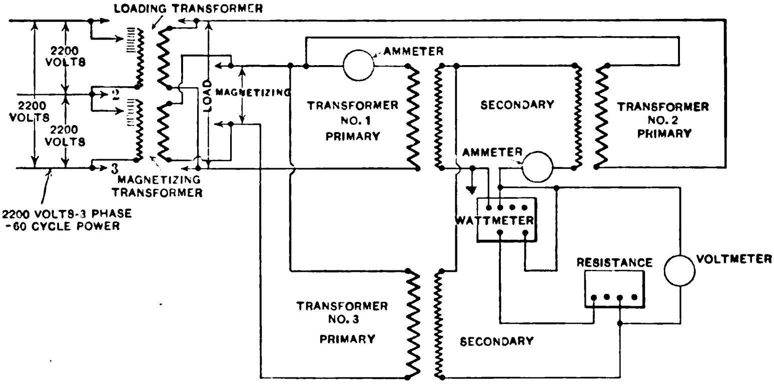

FIG. 1.—SCHEME OF CONNECTIONS FOR MEASURING COPPER LOSS AND IMPEDANCE VOLTS OF TRANSFORMER UNDER LOAD (OPPOSITION) AT DIFFERENT POWER FACTORS.

With a view to determining whether the conditions in the iron produce an appreciable change in the values of the short circuit losses of a transformer, the following method, based on equation (**17**), of measuring impedance volts and short circuit losses with load conditions was used. Two transformers were loaded by the opposition method. A third transformer of like characteristics was connected with its primary in multiple with that one of the two loaded transformers of which the short circuit losses and impedance under load condition was to be measured. The secondaries of the two transformers were connected so that the electromotive forces were opposed, and a wattmeter, the series coil of which was in the secondary circuit of the two loaded transformers had its shunt energized by the difference of the secondary electromotive forces of the loaded and unloaded transformers. The wattmeter then with proper corrections reads the short circuit loss corresponding to the condition of induction in the iron at the load that is given. The power factor of the load may be changed by exciting the loaded transformer from the different phases of a three-phase generator. (See Fig. 1.)

(4) Test Results

Tests were made on a 150-kv-a. 60-cycle transformer to ascertain if there were any variations in the values of the short circuit losses under different power factors of load and change in excitation. The results obtained are tabulated. (See Table 1.)

The first six results given in the table were obtained with exciting voltages 0, 500, 1000, 1500, 2000 and 2500; the losses being respectively 1164.4, 1164.4, 1164.4, 1169.4, 1176.4 and 1176.4 watts. The maximum variation in these values is a little over 1 per cent. The first value should be identical to the loss obtained by the short circuit test, which is 1136 watts; it is seen to be 2½ per cent higher. This difference is partly due to a difference in temperature of the windings at the time the two tests were made and partly to a slight difference in the magnetic characteristics of the loaded and unloaded transformers. The remaining results show a difference in the measured values at full load with power factors varying from 31 per cent to 99 per cent of a little over 2 per cent. This difference is due entirely to the rise in temperature of the windings during test. This also is the cause of the difference between the value at zero excitation and that at maximum excitation and 31 per cent power factor. The principal results of these tests are given below.

Short circuit loss obtained by standard method........	1136
" " " by method described, exciting volts zero..........................	1164
" " " maximum excitation 31 per cent power factor......	1175.4
" " " " " 99 per cent power factor......	1189.4

Tests were made on a transformer of smaller size with similar results.

(5) PRACTICAL FORMULAS

The following formulas are based on the preceding investigation.

REGULATION

$$I\,R = \frac{\text{short circuit losses}}{\text{rated output}} \times 100$$

$$I\,X = \frac{\text{reactance volts}}{\text{scondary rated voltage}} \times 100$$

PF = Power factor of load.

Per cent regulation $= (P.F.)\,I\,R + \sqrt{1 - (P.F.)^2}\,I\,X$ **(22)**

The following correction may be added where a higher degree of accuracy is required.

$$\text{Correction} = \frac{\{(P.F.)IX - \sqrt{1-(P.F.)^2}\,I\,R\}^2}{200} \qquad \textbf{(23)}$$

$I^2\,R$ AND STRAY LOSSES IN COPPER

If we define.

I_m = effective value of primary no load exciting current
I_2 = effective value of secondary load current
n_1 = number of primary turns
n_2 = number of secondary turns
R_1 = effective resistance of primary winding.

$$p = \frac{n_1\,I_m}{n_2\,I_2}$$

$$q = \frac{\left(\frac{n_2}{n_1}\,I_2\right)^2 R_1}{\text{Short circuit loss}}$$

Total loss in copper

$= \text{short circuit loss} \times (1 + 2\,p\,q\sqrt{1-(P.F.)^2})$ **(24)**

To illustrate this by an example; suppose a transformer has an exciting current of 10 per cent and its short circuit loss is 2 per cent what will be the correct copper loss at 80 per cent power factor supposing that the portion of the short circuit loss in the primary circuit is 60 per cent of the total value?

Per cent copper loss = per cent short circuit loss $\times (1 + 2 \times 0.1 \times 0.6 \times 0.6) = 2.14$ per cent.

The above formula omits the effect of the hysteresis angle which will slightly increase the correction but the amount added thereby is too small to be of any importance. It will be noted that at 100 per cent power factor the correction is zero, and since efficiencies are normally figured at this power factor, it will be necessary to make a correction only when efficiencies are required at low power factors.

TABLE I.

SHORT CIRCUIT LOSS AND IMPEDANCE VOLTS OBTAINED BY METHOD SHOWN IN FIG. 1, WITH VALUES OF IMPRESSED VOLTAGE RANGING FROM ZERO TO NORMAL RATED VALUE, AND WITH POWER FACTORS FROM 99 PER CENT DOWN TO 31 PER CENT. FREQUENCY 60 CYCLES.

Primary volts	Primary amperes	Secondary amperes	Power factor of load	Watts loss	Impedance volts
0	60.0	13.63	30.9	1164.4	276
500	60.2	13.63	30.9	1164.4	277
1000	60.7	13.63	30.9	1164.4	278
1500	60.9	13.63	30.9	1169.4	277
2000	61.3	13.63	30.9	1176.4	278
2500	62.6	13.63	31.6	1176.4	277
2500	58.0	13.63	*32.4	1176.4	276
2500	59.2	13.63	65.6	1189.4	276
2500	61.8	13.63	*69.0	1189.4	279
2500	61.4	13.63	99.2	1189.4	278
2500	59.4	13.63	*99.3	1179.4	277

*The differences in the wattmeter measurements given in this table are due to the increase in temperature of the windings during the time the test was in progress. Satisfactory measurements of resistance were not obtained and therefore no correction has been made in the readings. In this case the transformer was receiving power at the secondary terminals, instead of at the primary terminals.

(6) RECOMMENDATIONS

In view of the test results given in Section 4 and others that have been obtained from time to time, the authors feel justified in recommending that the old standard method of obtaining short circuit losses in transformers be retained. In special cases the method described in this paper may be used but on account of the inconvenience of applying it, its general use is not recommended. It is recommended that the copper loss and regulation be calculated from the short circuit loss and impedance voltage. The correction to the short circuit loss to obtain the copper loss under load may be made acording to the practical formula (**24**) which is derived from equation (**21**). The regulation may be figured according to formula (**22**), the correction for the quadrature component given by formula (**23**) being used where required. This well known formula is based on equation (**17**) and gives very nearly exact values when the correction for the quadrature component is used. It is very much simpler than other less accurate formulæ that are in common use.

LIST OF SYMBOLS USED IN THEORETICAL DISCUSSION

L_1 = Primary open circuit inductance
L_2 = Secondary open circuit inductance
L_0 = Inductance of load
M = Mutual inductance between primary and secondary
R_1 = Primary resistance
R_2 = Secondary resistance
R_0 = Resistance of load
i_1 = Instantaneous value of primary current
i_2 = Instantaneous value of secondary current
e_1 = Primary impressed e.m.f.
p = $2\ \pi \times$ frequency
$\overset{\vee}{I}_1$ = Complex variable expression for primary current
$\overset{\vee}{I}_2$ = Complex variable expression for secondary current
$\overset{\vee}{I}_m$ = Complex variable expression for primary open circuit current
$\overset{\vee}{E}_1$ = Complex variable expression for primary impressed e.m.f.
$\overset{\vee}{E}_2$ = Complex variable expression for secondary normal e.m.f. under load.
$\overset{\vee}{E}_0$ = Complex variable expression for secondary no load e.m.f.
I_1 = Effective or root mean square value of primary current
I_2 = Effective or root mean square value of secondary current
I_m = Effective or root mean square value of primary open circuit current
$|I_1|_n |I_2|_n |I_m|_n$ represent the effective value of the *n*th harmonic of the quantities $\overset{\vee}{I}_1\ \overset{\vee}{I}_2\ \overset{\vee}{I}_m$

$\hat{Z}_a$ = For simple sine waves, the effective impedance of the primary circuit under load. For any periodic wave it represents an operation equivalent to impedance on each harmonic of the wave, the value of the impedance changing with each harmonic.

$\check{Z}_0$ = Similar operation to Z_a but representing impedance of load.

R_a L_a = Resistance and inductance corresponding to Z_a

R_b L_b = Resistance and inductance corresponding to short circuit impedance.

R_c L_c = Resistance and inductance corresponding to impedance of secondary with primary short circuited.

ϕ_n = Phase angle for nth harmonic.

The symbols used in Section 5 of this paper are defined in the text.

LOAD TESTS ON TRANSFORMERS

BY

J. J. K. MADDEN

Presented under the auspices of the

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LOAD TESTS ON TRANSFORMERS

BY J. J. K. MADDEN

Abstract of Paper

The paper discusses the different recognized methods of conducting load tests on more than one transformer without applying actual load, also methods of making such tests where one single phase transformer only is available.

The actual loading of transformers for test purposes is very expensive, and therefore, the motor-generator method is most suitable whenever more than one single-phase transformer or any number of three-phase transformers are considered. The load and excitation is applied to the high voltage or to the low voltage windings depending upon the rating, etc. of the transformers.

When one unit only is available a heat test may be made which consists in applying intermittently an over-voltage core loss with an over-current impedance loss. Approximate values of temperature only are obtained by a combination of an ultimate open-circuit heat run followed by an ultimate short-circuit heat run, and should be used only where not expedient to use the other method.

Tables 1 to 8 inclusive show results of the above methods on different transformers as compared with dead load and motor-generator methods.

Upon the characteristics of the transformer will depend the over-voltage and over-current for the intermittent runs, so as not to injure the transformer and also to eliminate errors.

All the motor-generator methods, Figs. 1 to 6 inclusive, are standard and therefore have been recommended.

When one single-phase transformer is considered, the intermittent run method is recommended and this method may be modified so as to obtain a closer refinement.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26–28, 1913.

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(*Subject to final revision for the Transactions.*)

LOAD TESTS ON TRANSFORMERS

BY J. J. K. MADDEN

Load tests on transformers may be conducted in several ways all of which are intended to approximate as nearly as possible the operating conditions of the transformers so far as temperature rise is concerned.

A run with actual load might be made by using water rheostats, but as this would be very expensive, some form of motor-generator method is ordinarily used, which will give approximately the same heating.

Fig. 1 shows connections for testing two similar single-phase transformers by the "motor-generator" method. The low voltage windings are connected in multiple, to which normal voltage is applied. An auxiliary transformer connected in series with the high-voltage windings supplies the impedance losses. The same method may be used for any even number of transformers, and load and excitation may be applied to the same windings or reversed from the order shown in the illustration. The rated voltage of the windings will determine the arrangement.

Fig. 2 shows connections for testing three similar single-phase transformers, or one or more three-phase transformers if delta connected.

Fig. 3 shows connections for testing two three-phase transformers. The transformers may be connected either delta or Y, but some means of regulation on the loading side must be included so as to be able to balance the load current independently in each phase.

Fig. 4 shows the same connections as Fig. 1, except that the low-voltage winding has several independent circuits. Excitation is applied to one winding only, and the loads are properly distributed by inserting reactance, if necessary, in the circuits so as to balance the loads carried by each winding.

Fig. 5 shows connections for testing two similar polyphase Scott-connected transformers. Excitation and load are applied to the three-phase side.

Fig. 6 shows connections for testing two similar single-phase transformers suitable for two-phase-three-phase operation. Load and excitation are applied to the windings used for the two-phase side, while an extra source of supply of current furnishes the 15 per cent additional current on the three-phase side. This will give the conditions obtained when the transformers are operated Scott-connected. This method is used on transformers which do not have the halves of the two-phase windings connected in multiple. When the halves are connected in multiple both transformers should be connected as mains and should be furnished with load current equal to 115 per cent of their normal single-phase rating, as in Fig. 1.

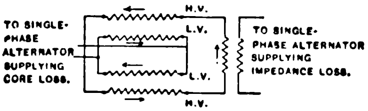
TO SINGLE-PHASE ALTERNATOR SUPPLYING CORE LOSS.
H.V.
L.V.
L.V.
H.V.
TO SINGLE-PHASE ALTERNATOR SUPPLYING IMPEDANCE LOSS.

FIG. 1

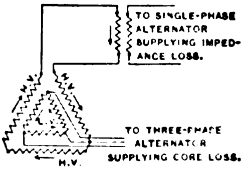
TO SINGLE-PHASE ALTERNATOR SUPPLYING IMPEDANCE LOSS.
H.V.
H.V.
TO THREE-PHASE ALTERNATOR SUPPLYING CORE LOSS.
H.V.

FIG. 2

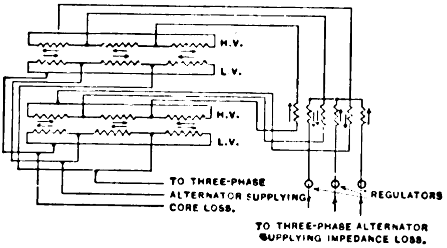
H.V.
L.V.
H.V.
L.V.
TO THREE-PHASE ALTERNATOR SUPPLYING CORE LOSS.
REGULATORS
TO THREE-PHASE ALTERNATOR SUPPLYING IMPEDANCE LOSS.

FIG. 3

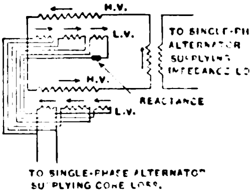
H.V.
L.V.
TO SINGLE-PHASE ALTERNATOR SUPPLYING IMPEDANCE LOSS.
H.V.
REACTANCE
L.V.
TO SINGLE-PHASE ALTERNATOR SUPPLYING CORE LOSS.

FIG. 4

The "motor-generator" or "opposition" method cannot, of course, be employed when one single-phase transformer is involved, and since the actual loading of such a transformer on water rheostats is not always feasible, it is the idea of this paper to suggest, particularly, methods to be used on such a transformer. These methods must be such that they do not entail a great loss of power and yet approximate as nearly as possible the operating conditions ot the transformer.

These methods for testing single transformers may be classed as follows:—

a. Intermittent runs.

b. Ultimate open circuit and short circuit runs.

a. The principle of the intermittent run will be understood from the following considerations: The average temperature rise of oil depends upon the total watts loss in the transformer, and is independent of where the loss takes place. Therefore, if a loss equal to the total loss is intermittently placed in the iron and in the copper by alternating an over-voltage core loss run with an over-current impedance run, the oil should have a perfectly normal rise. The temperature of the copper, however, would fluctuate between maximum and a minimum values because during the core loss run the copper would be cooling towards the oil temperature, and during the impedance run, the copper temperature would be rising.

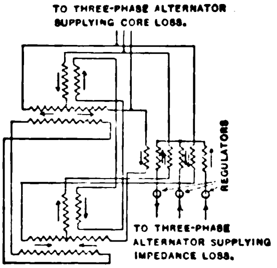
TO THREE-PHASE ALTERNATOR SUPPLYING CORE LOSS.
REGULATORS
TO THREE-PHASE ALTERNATOR SUPPLYING IMPEDANCE LOSS.

FIG. 5

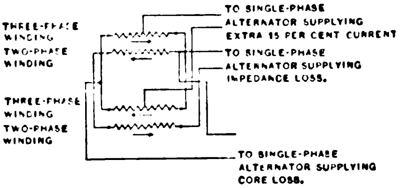
THREE-PHASE WINDING
TWO-PHASE WINDING
THREE-PHASE WINDING
TWO-PHASE WINDING
TO SINGLE-PHASE ALTERNATOR SUPPLYING EXTRA 15 PER CENT CURRENT
TO SINGLE-PHASE ALTERNATOR SUPPLYING IMPEDANCE LOSS.
TO SINGLE-PHASE ALTERNATOR SUPPLYING CORE LOSS.

FIG. 6

If, however, the integrated watt-hour loss over the complete cycle of the intermittent run is equal to the normal integrated copper loss for the same time, the mean of the maximum and minimum temperatures attained by the copper above oil would be equal to the normal copper rise above oil. If the time of each cycle is made small enough, the difference between the maximum temperature rise and the normal temperature rise above oil is small enough to neglect, in which case this maximum rise would be taken as the measure of the normal temperature rise of the copper. Actual tests here given show that if the periods are reduced to five minutes, the difference between the two temperatures is less than the errors involved in testing. Moreover, the difference is on the safe side since it always will tend to show temperature slightly greater than the normal.

It is also evident that if in the last copper run the time interval were cut in half, the maximum rise at the instant of shut down would be much closer to the normal rise than if the run had been continued for the complete cycle.

Tests were made in which each run was continued until the top oil showed a constant temperature rise of not more than one degree within two or three hours. The run was then stopped at the end of a cycle or half period and the resistance of both windings taken.

Fig. 7 shows the connections for testing one transformer by the intermittent run method. Two oil switches are so arranged that when the one in the core loss circuit is closed the one in the impedance loss circuit is tripped, as is also the short circuiting switch which is in use during the impedance run. The impedance and short circuit switches are combined, and interlocked with the core loss switch so as to make it impossible to apply core loss voltage without the other switch first being opened.

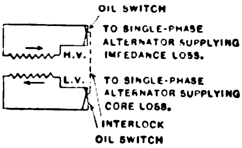
OIL SWITCH
TO SINGLE-PHASE ALTERNATOR SUPPLYING IMPEDANCE LOSS.
H.V.
L.V.
TO SINGLE-PHASE ALTERNATOR SUPPLYING CORE LOSS.
INTERLOCK
OIL SWITCH

FIG. 7

b. The second method which consists in taking separately ultimate short circuit and open circuit runs, is based on the idea that the temperature rises in windings and oil are directly proportional to the heat energy which is being dissipated. For example, if 100 watts total loss causes the oil to rise 10 deg. above air, a total loss of 50 watts should cause the oil to rise 5 deg. above air, and for the same reason doubling the loss in the winding should double also the temperature rise of the winding above the oil into which it dissipates its heat.

Granting this assumption for a moment, suppose a transformer, in which the copper loss equals the core loss under normal load, attains an ultimate temperature rise of 40 deg. oil above air and 5 deg. copper above oil. Under an ultimate core loss run, the watts loss being only half the total, the oil rise should be 20 deg. above air and the copper being idle, would be at oil temperature. Similarly, an ultimate impedance run would give an oil rise of 20 deg. above air and a copper rise of 5 deg. above oil. The ultimate rise for either oil or copper for a load run is then obtained by adding together the two rises respectively, resulting from the ultimate short circuit and open circuit runs.

Tests were made to prove the correctness of this hypothesis on 25- and 500-kw. transformers, and in both cases the values obtained by adding the temperature of the separate runs, gave values considerably higher than the normal run. In both cases, the sum of the ultimate oil rises obtained from the two is about 5 deg. greater than the oil rise obtained in an opposition run. The discrepancy may be due to the fact that the ability of the air in contact with the walls of the transformer tank to cool the transformer is not directly proportional to the temperature difference between the oil and the air, and also that the radiation from the tank, increases more rapidly than the temperature rise.

Whatever may be the explanation, however, the tests given in tables II and VI show conclusively that this method does not closely approximate the operating conditions of a transformer, but the results are always higher than those obtained under normal operating conditions. This method should be used therefore only in cases where it would not be expedient to use another method. These runs shown in tables II and VI were continued until the top oil showed a constant temperature rise of not more than one degree in two or three hours of the run.

Table I gives data of a 25 kv-a. transformer operated under the following conditions:

1. Motor-generator method with a similar transformer.
2. Dead load on a water-box.
3. Voltage (corresponding to 371 per cent of normal core loss at 25 deg. cent.) for 2¾ minutes and current (corresponding to 150 per cent normal impedance loss at 25 deg. cent.) for 7¼ minutes.
4. Voltage (corresponding to 198 per cent of normal core loss at 25 deg. cent.) for 5 minutes and current (corresponding to 200 per cent normal impedance loss at 25 deg. cent.) for 5 minutes.
5. Voltage (corresponding to 139 per cent of normal core loss at 25 deg. cent.) for 7¼ minutes and current (corresponding to 379 per cent normal impedance loss at 25 deg. cent.) for 2¾ minutes.

In the above runs (3) (4) and (5) each cycle had a duration of ten minutes. It will be seen that the cyclic runs give results within 3 per cent of actual operating temperatures.

Table II gives ultimate open-circuit and short-circuit runs on the 25-kv-a. transformer in which voltage and current corresponding to 25 deg. cent. losses were held as in table I.

Table III presents the data of table I and II in a different form, in order to point out the actual losses, core, copper and total, held on these tests.

Tables IV and V give data of a 500-kv-a. transformer, as follows.

1. Intermittent runs in which 199 per cent of normal impedance loss and 196 per cent of normal core loss were held for periods of 5, 10, 15, 20 and 30 minutes. The cycle was then reversed, *i. e.*, core loss first, followed by impedance loss.

TABLE I

Rating H-60-25 1100/2200-110/220

Cycles of run	Motor generator run	Dead load run	Intermittent runs		
			2¾ min. core loss 7¼ min. imp. loss	5 min. core loss 5 min. imp. loss	7¼ min. core loss 2¾ min. imp. loss
Length of heat run—hours..	22	17	24	20	24
Initial load applied.					
Core loss..............	145.4	145.4	539	288	302
Imp. loss..............	320.5	320.5	479	641	1212
Rise of high voltage wind in deg. cent..............	41.3	40.5	41.4	39.5	42.1
Rise of low voltage wind in deg. cent..............	43.2	41.2	42.1	40.2	43.5
Oil rise deg. cent...........	29	29	31	27	32

NOTE.—Normal core loss at 25 deg. cent. = 145.4 watts.
Normal impedance loss at 25 deg. cent. = 320.5 watts.
All losses based on cold wattmeter readings.
Heat runs were made by holding voltage and current constant throughout each cycle of intermittent runs; also on motor generator and dead-load runs.

TABLE II

RATING H-60-25-1100/2200-110/220

	Open circuit run	Short circuit run
Length of run—hours...............	10	18
Initial load applied.		
Core loss.......................	145.4	——
Imp. loss.......................	——	320.5
High voltage wind. rise in deg. cent....	8.8	30.8
Low voltage wind. rise in deg. cent..	11.2	34.4
Oil rise in deg. cent................	9	24

See Note under Table I regarding losses.

In each case the cycles were equally divided, *i.e.* 5 minutes impedance loss and 5 minutes core loss, etc. The percentages are based on normal wattmeter readings at ultimate full load operating temperature.

2. Motor-generator method with a similar transformer.

Table VI gives open-circuit and short-circuit ultimate temperature runs on the 500-kv-a. transformer.

Table VII gives results of intermittent runs of 10, 30, and 60 minute cycles, the periods for each being half this time. These runs are in all respects similar to those of table V, with the exception that the run was cut off at the middle point of the impedance period. These results are seen to be in very close accord with those secured on the motor-generator run.

TABLE III

RATING H-60-25-1100/2200-110/220

		Per cent normal	Per cent total normal	Per cent time	Per cent total energy normal	Cold normal core loss at 25 deg.cent	Cold normal impedance watts at 25 deg. cent.
Core loss	Intermittent runs 2¾ min.	371	115.5	27.5	102	145.4	320.5
Imp. loss	7¼ "	150	103	72.5	109		
Core loss	5 "	198	61.8	50	99		
Imp. loss	5 "	200	137.5	50	100		
Core loss	7¼ "	139	43.4	72.5	101		
Imp. loss	2¾ "	379	260	27.5	104		
Core loss	Motor generator	100	31.2	100	100		
Imp. loss	run	100	68.8	100	100		
Core loss	dead load	100	31.2	100	100		
Imp. loss	run	100	68.8	100	100		
Core loss	Open circuit	100	31.2	100	100		
Imp. loss	run	—	—	—	—	—	—
Core loss	Short	—	—	—	—	—	—
	circuit	—	—	—	—	—	—
Imp. loss	run	100	68.8	100	100		

All percentages based on 25 deg. cent. wattmeter readings.

Heat runs were made by holding voltage and current constant through each cycle, also for ultimate runs.

Table VIII presents the data of tables IV to VII inclusive, in a different form in order to point out the actual losses, core, copper and total used in these tests, in comparison with the normal.

In order to secure more reliable results, these two types of runs were made on two transformers, differing widely both in capacity and in the proportioning of losses. While the 25 kv-a. core and copper losses are proportioned 1 to 2.2 respectively, the 500 kv-a. losses are approximately 1 to 1.1.

It will be noted that these tests were conducted on self-cooled, oil-insulated transformers, but there is no apparent reason why such runs would not also be approximately correct for other types. It will be interesting to have the assumption checked on other types of transformers.

Referring to the intermittent runs, it is seen that in the case of the 25-kv-a. transformer, a specified voltage and current were held constant, while on the 500-kv-a. watts were held constant. Excluding the question of stray losses, the two methods agree in applying the proper loss to core and copper respectively. However, due to the fact that stray losses are affected by temperature at a different rate than the resistance losses, when current is held constant, the proper value of losses will not be present at ultimate operating temperatures. On the other hand, due to the fact that stray losses increase at a less rate than the resistance loss, with increasing current, when watts are held constant, the losses at ultimate operating temperature ar note

TABLE IV
RATING H-60-500-11000-2300

	Intermittent runs				
Cycles of run	5 min. imp. loss 5 min. core loss	10 min. imp. loss 10 min. core loss	15 min. imp. loss 15 min. core loss	20 min. imp. loss 20 min. core loss	30 min. imp. loss 30 min. core loss
Average length of runs—hrs.	5	6	6	5	4
Load applied.					
Core loss	6930	6930	6930	6930	6930
Imp. loss	6335	6335	6335	6335	6335
Rise of high voltage winding in deg. cent.	53.5	53.9	50.9	49.9	48.3
Rise of low voltage winding in deg. cent.	48.6	48.0	49.5	55.4	52.8
Rise of oil in deg. cent.	50	50	50	50	49

NOTE.—The rises are averages of two or three runs.
Normal core loss at 74 deg. cent. = 3540 watts.
Normal copper loss at 74 deg. cent. = 3175 watts.
All losses based on hot wattmeter readings.
Heat runs were made by holding wattmeter readings constant throughout each cycle.

TABLE V
RATING H-60-500-11000-2300

Cycles of run	Intermittent runs					
	5 min. core loss 5 min. imp. loss	10 min. core loss 10 min. imp. loss	15 min. core loss 15 min. imp. loss	20 min. core loss 20 min. imp. loss	30 min. core loss 30 min. imp. loss	Motor generator run
Average length of heat run hours..................	12	6	5	10	6	13
Load applied.						
Core loss..............	6930	6930	6930	6930	6930	3540
Imp. loss..............	6335	6335	6335	6335	6335	3175
Rise of high voltage winding in deg. cent..............	56.1	57.1	57.5	59.4	62.8	53.6
Rise of low voltage winding in deg. cent.............	46.7	52.0	52.2	54.3	58.5	45.9
Rise of oil in deg. cent.....	50	50	50	50	50	50

NOTE.—See Note, Table IV.

TABLE VI
RATING H-60-500-11000-2300

	Open circuit run	Short circuit run
Average length of run-hours........	24	12
Load applied.		
Core loss......................	3540	——
Imp. loss......................	——	3175
Rise of high voltage winding in deg. cent............................	27.8	32.5
Rise of low voltage winding in deg. cent.............................	28.2	34
Rise of oil in deg. cent..............	31	25

NOTE.—See Note under Table IV regarding losses.

TABLE VII
RATING H-60-500-11000-2300

	5 min. core loss 5 " imp. "	15 min. core loss 15 " imp. "	30 min. core loss 30 " imp. "
Average length of run—hours...	8	8	13
Load applied.			
Core loss.................	6900	6900	6900
Imp. loss.................	6340	6340	6340
Rise of high voltage winding in deg. cent..................	50.4	52	53.9
Rise of low voltage winding in deg. cent..................	44.1	44.8	46.3
Rise of oil in deg. cent.........	48	48	48

See Note under Table IV

The above heat runs were shut down and temperatures, etc. measured at the middle point of the last impedance period.

TABLE VIII

RATING H-60-500-11000-2300

		Per cent normal	Per cent total normal	Per cent time	Total energy per cent normal	Cold normal core loss at 26.5 deg. cent	Cold normal impedance watts at 25 deg. cent.	Hot normal core loss at 74 deg. cent.	Hot normal impedance watts at 74 deg. cent.
Core loss.	Intermittent run	196	103	50	98	3770	2710	3540	3175
Imp. loss.		199	94.1	50	99.5				
Core loss.	Motor-generator run	100	47.3	100	100				
Imp. loss.		100	52.7	100	100				
Core loss.	Open circuit run	100	47.3	100	100				
Imp. loss.		—	—	—	—	—			
Core loss.	Short circuit run	—	—	—	—				
Imp. loss.		100	52.7	100	100				

NOTE.—All losses based on hot wattmeter readings.

Heat runs were made by holding wattmeter readings constant through each cycle, and also for ultimate runs.

distributed exactly as under normal conditions, although the total may be correct. It would appear that the latter method is the better of the two, although no serious errors will probably result from either, except possibly in the case of transformers possessing very large stray losses.

The two sets of runs will also be seen to differ as to the relative duration of core and copper periods. In the case of the 500-kv-a. machine, the complete cycle was divided equally between core and copper, viz. double losses were held for half the cycle on core and copper respectively. On the 25-kv-a. machine, the complete cycle was divided unequally between core and copper, the losses in each case being inversely proportional to the time. Although from a general standpoint, it would be simpler and more convenient to specify equal core and copper periods, yet cases will often arise where it will be of considerable advantage to increase either the core or copper period corresponding to either high flux or current densities in the particular design in question. This is due not only to possibility of abnormal local heating, but also to possible errors introduced, for instance, as a high exciting current on the core loss period. In such a case, it is practicable to eliminate the error by reducing the energy loss on copper period by the amount held on copper in core loss period. Similarly, in case of appreciable core loss on copper loss period, reduction in energy loss on core period can be made. The error due to high exciting current can also be eliminated by an increase in frequency.

In the case of the 500-kv-a. unit, various periods for the complete cycle from ten minutes to one hour were tried out, all runs giving fairly good results. Although from the standpoint of switching, etc. it is of advantage to employ cycles of considerable duration, yet care must be taken not to jeopardize the transformer by local heating in any part.

It will be seen from the tabulated data that more consistent results were secured by cutting off the load on the last cycle at the middle of the copper period than by cutting off at the end of the cycle. This is, of course, much more correct although somewhat in error due to the fact that the rate of increase in temperature with a given load diminishes with the time the load is applied. If desired, still greater refinement may be secured by making a change to shorter cycles, say of ten minutes, at the middle point of copper period, when constant cyclic conditions have first been reached.

RECOMMENDATIONS

Since the "motor-generator" method of making heat runs which has been universally used is satisfactory, this method is recommended, whenever more than one single-phase transformer, or when one or more three-phase transformers are available.

Based on the above discussion, and tests presented in the attached tables, the following method is recommended for obtaining as near as possible the normal temperature rise under operating conditions of one single-phase transformer.

By suitable means, raise the transformer windings to estimated operating temperature, after which measure normal core loss and normal impedance loss. Select such a time for the cycle, say thirty minutes, as will avoid excessive local heating. Divide the cycle into two periods, which are inversely proportional to watts loss to be held in the respective periods Unless considerations such as abnormal exciting current (which can usually be obviated by raising the frequency) prevent, hold total normal loss of machine first on core and then on copper. Alternate the core and copper periods until the temperature of the cooling medium is constant. Cut off run at middle point of copper period, and record temperatures and resistances. Closer refinement may be obtained by reducing the length of the cycle to, say ten minutes, at the end of the run noted above.

THE TEMPERATURE RISE OF STATIONARY INDUCTION APPARATUS AS INFLUENCED BY THE EFFECTS OF TEMPERATURE, BAROMETRIC PRESSURE AND HUMIDITY OF THE COOLING MEDIUM

BY

J. J. FRANK and W. O. DWYER

Presented under the auspices of the

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INFLUENCE OF THE TEMPERATURE, BAROMETRIC PRESSURE AND HUMIDITY OF THE COOLING MEDIUM ON THE TEMPERATURE RISE OF STATIONARY INDUCTION APPARATUS

BY J. J. FRANK AND W. O. DWYER

ABSTRACT OF PAPER

For some time it has been felt that the corrections to be applied to the temperature rise of stationary induction apparatus, when operating under conditions differing from standard, needed some little revision.

The theoretical considerations governing the dissipation of heat from this class of apparatus are given briefly in the first part of this paper and the influence of temperature, barometric, pressure and humidity on the emissive constants are also briefly discussed. It was expected that the presence of moisture would have considerable influence on the temperature rise of air-cooled apparatus but a theoretical analysis shows that for ordinary room temperatures, the effect can be small even if the atmosphere is saturated. Exception is made, of course, to the case of fog-laden air.

The second part of the paper is devoted to a presentation of the results of some tests made to check these conclusions. Some of these tests were made under artificially produced conditions and some under natural conditions.

In the last part of the paper recommendations for corrections to be applied and precautions to be taken are given. Wherever possible, apparatus should be tested under as nearly the same conditions as those under which it is to operate. In case it is impossible to maintain these conditions the following corrections should be applied:

I. *Variations in Room Temperature.*

On all classes of apparatus except air-blast no correction be applied. On air-blast the present recommendations of A. I. E. E. be followed.

On water-cooled apparatus the reference be the in-going water and this temperature and that of the room should be as near 25 deg. cent. as possible.

II. *Variation in Barometric Pressure.*

For self-cooled apparatus present A. I. E. E. recommendations be followed.

For water-cooled apparatus no correction be applied.

For air-blast apparatus double the present A. I. E. E. recommendations be followed.

III. *Variations in Humidity.*

No corrections be applied for variations in humidity except in case of fog-laden air.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26–28, 1913.*

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(*Subject to final revision for the Transactions.*)

THE TEMPERATURE RISE OF STATIONARY INDUCTION APPARATUS AS INFLUENCED BY THE EFFECTS OF TEMPERATURE, BAROMETRIC PRESSURE AND HUMIDITY OF THE COOLING MEDIUM

BY J. J. FRANK AND W. O. DWYER

The proper correction to be applied to the temperature rise of apparatus when tested or operating under conditions differing from those which have been accepted as a reference standard has been investigated and discussed, and various conclusions drawn.

It is the purpose of this discussion to present a short theoretical resume of the considerations that enter into the above together with the results of an investigation that has been made on some transformers under test to verify the conclusions which have been reached.

The room temperature to be considered as a reference standard as given in the Standardization Rules of the A. I. E. E. is 25 deg. cent., as stated in section 268, reading as follows:

" Room Temperature. The rise of temperature should be referred to the standard condition of a room temperature of 25 deg. cent."

The barometric pressure to be considered standard as given in the Standardization Rules of the A. I. E. E. is 760 mm. (29.92 in.) as stated in Section 270 and 271, reading as follows:

" Barometric Pressure. Ventilation. A barometric pressure of 760 mm. and normal conditions of ventilation should be considered as standard, and the apparatus under test should neither be exposed to draught nor enclosed, except where expressly specified. The barometric pressure needs to be considered only when differing greatly from 760 mm.

"Barometric Pressure Correction. When the barometric pressure differs greatly from the standard pressure of 760 mm. of mercury, as at high altitudes, a correction should be applied. In the absence of more nearly accurate data, a correction of one per cent of the observed rise in temperature for each 10 mm. deviation from the 760 mm. standard is recommended. For example at a barometric pressure of 680 mm. the observed rise of temperature is to be reduced by $\frac{760-680}{10} = 8$ per cent."

In artificially cooled apparatus no mention is made of the proper correction to be applied when the temperature of the cooling medium differs from the temperature of the enveloping air. In water-cooled apparatus no instructions are given for a standard reference temperature of the water. In apparatus cooled by air blast, no instructions are given in case the supply of air is taken from a source other than the room in which the apparatus is being tested.

No correction for changes in humidity are given.

General Theory of Dissipation of Heat from a Body

The rate of dissipation of heat from a body is dependent upon

1. Radiation
2. Convection
3. Conduction

The transfer and final dissipation of heat is accomplished in several stages, each of which involves some or all of the above factors, *i.e.*, radiation, convection and conduction. We may roughly group the steps in stationary induction apparatus as follows:

a. From the core or from the conductor through the insulation to the cooling medium in contact with it.

b. Through the cooling medium to the case, tank or cooling coils.

c. Through the casing or cooling coils to the medium which finally carries away the heat.

Classification based on the several methods of cooling divides stationary induction apparatus into five groups as follows:

(i) *Self Cooled Natural Draft.* In this class of apparatus the cooling is dependent upon (a) only. The heat is carried along the conductor or through the conductor to its exposed portion by conduction, through the insulation by the same process, and dissipated by radiation and convection.

(ii) *Self Cooled Oil Insulated.* In this class of apparatus steps (a), (b) and (c) are involved. The transfer of heat is accomplished in this case by conduction through the insulation, convection and some radiation through the oil and convection and radiation from the tank.

(iii) *Artificially Cooled by Circulation of Oil.* In this class of apparatus steps (a), (b) and (c) are involved. The transfer of heat is accomplished by conduction through the insulation, convection and some radiation through the oil, and convection and radiation from (a) external radiators (b) water-cooled coils.

(iv) *Artificially Cooled Water Cooled Apparatus.* In this class of apparatus the transfer of heat is similar to that in (ii) with the modification that most of the heat is carried away by convection by water circulated in cooling coils.

(v) *Artificially Cooled Air-Blast Apparatus.* In this class of apparatus the cooling may be dependent upon (a) only, where the air blast is in direct contact with the windings and core or the cooling may be dependent on (a), (b) and (c), in such apparatus in which the blast of air comes in contact with the outside of the case or tank.

RADIATION

The quantity of heat dissipated by radiation may be expressed by Stefan-Boltzman's Law by

$$W_R = K\,(T_1^4 - T_2^4) \qquad (1)$$

Where K = constant depending upon the diathermancy or transmissive power of the medium, upon the nature and color of the surface and upon the size of the enclosure in which body is dissipating heat.

T_1 = absolute temperature of the apparatus.
T_2 = absolute temperature of surrounding objects.

CONVECTION

The calculation by mathematical considerations of the amount of energy dissipated by convection requires the use of one or more empirical constants. Much work along this line has been done by Prof. Kennelly and Dr. Langmuir, the results of the latter's investigations being published in the *Physical Review* and the A. I. E. E. PROCEEDINGS.*

These investigations have been made for the most part on the dissipation of energy from fine wires at high temperatures where the amount dissipated by radiation is very small. Dr. Langmuir has shown, however, that in the dissipation from plane surfaces where the radiation factor is considerable the formulas developed may be used with excellent results.

Dr. Langmuir's theory is that the dissipation of heat by convection occurs by conduction through a film of adhering gas, the energy being conducted through this film by molecular diffusion to the moving convection currents of the surrounding gas and so carried away. Further the results of his experiments show that the thickness of this film is constant (0.43 cm.) (for constant room temperature and pressure) and that the dissipation of energy by convection is almost entirely dependent upon the thickness of this conducting film.

While no data are given on the relative values of dissipation by convection from horizontal and vertical plane surfaces, the experimental values as obtained from wires show that the convection is somewhat less for vertical wires than for horizontal.

This difference will be more pronounced in case of plane surfaces but the decreased efficiency will be more than compensated for by the flue or chimney action where the convection currents are constrained to move in certain spaces such as ducts, corrugations, flues, etc. For this type of surface the effectiveness of dissipation by convection will probably be greater than for horizontal plane surface, providing that the surface does not become so complicated that friction will seriously affect the convection currents.

Assuming that the dissipation of heat by convection takes place by conduction through a film of adhering gas, Dr. Langmuir has developed a formula for this of the form

$$W_c = \frac{\phi_1 - \phi_2}{B} = \text{watts dissipated per sq. cm.}$$

Where B = thickness of adhering film and ϕ is a function of T of the form

$$\phi = 1.93 \times 10^{-5} (1 + 0.00012\, T) \left[2/3\, T^{3/2} - 248\, T^{1/2} + 124^{3/2} \tan^{-1} \sqrt{\frac{T}{124}} \right] \qquad (2)$$

for air.

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*PROCEEDINGS A. I. E. E., June, 1912.

CONDUCTION

Conduction consists in the transfer of heat from one part of one body to another part of same body or from one body to another without any bodily transfer.

The amount of energy transferred by conduction is proportional to the specific heat resistance, to the density of the heat flux and to the length of the path, *i.e.* the rate of transmission of heat by conduction is proportional to the gradient or fall of temperature per unit length of path along the lines of flux flow.

$$W_d = \frac{K\,(T_1 - T_2)\,A\,t}{l} \text{ (for uniform gradient)} \qquad \textbf{(3)}$$

Where t = Time
A = Area
l = Length
K = Conductivity

EFFECTS OF TEMPERATURE OF COOLING MEDIUM ON HEAT DISSIPATION

Section 269 of the A. I. E. E. Standardization Rules covers the correction to be applied to the temperature rise of apparatus when the reference temperature varies from 25 deg. cent. This rule reads:

" If the room temperature during test differs from 25 deg. cent. correction on account of difference in resistance should be made by changing the observed rise of temperature by one-half per cent for each degree centigrade."

The correction as applied means an increase of one-half of one per cent per degree in the observed rise when room is below 25 deg. cent. and a decrease of one-half of one per cent if the room temperature is greater than 25 deg. cent. The reference of 25 deg. cent. refers to a constant room temperature, a condition which is hard to maintain in practice. No provision is made for applying correction when room temperature is varying or for correction for artificially cooled apparatus.

a. *Influence of Room Temperature on Radiation.* From equation (**1**) the quantity of heat dissipated by radiation from a hot body at temperature T_1 to surrounding objects at temperature T_2 is given by

$$W_R = K\,(T_1^4 - T_2^4)$$

It is apparent from the nature of the equation that W_R will increase with T_2 for a constant difference between T_1 and T_2 or in other words, for a given rise above room temperature, more watts will be dissipated the higher the room temperature or the dissipation of a given quantity of heat by radiation will be accompanied by a less rise above room temperature the higher the room temperature.

Fig. 1 gives values of $T_1^4 - T_2^4$ for constant rises above different temperatures of surrounding objects. An inspection of these curves will show that for a 40 deg. rise at 0 deg. cent. $T_1^4 - T_2^4$ is 400×10^8, while for the same rise at 60 deg. cent. the value of $T_1^4 - T_2^4$ is 720×10^8, an increase of 80 per cent in the effectiveness of radiation. Consequently the same watts dissipated by radiation for a 40 deg. rise above 0 deg. cent. gives only a 24 deg. cent. rise at 60 deg. cent.

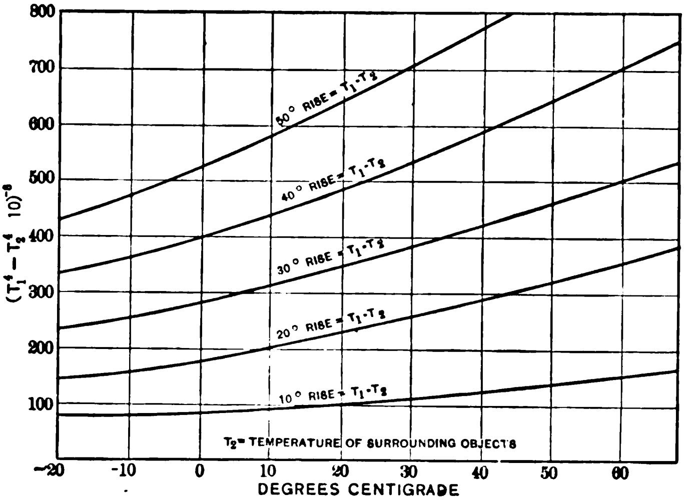

FIG. 1

Fig. 2 gives the watts loss per sq. cm. dissipated by radiation for different rises above various room temperatures assuming $K = 4.78 \times 10^{-12}$ *i.e.* 90 per cent value of a perfect black body.

b. *Influence of Room Temperature on Convection.* The amount of energy dissipated by convection at constant room temperature (30 deg. cent.) is given in equation (2)

$$W_c = \frac{\phi_1 - \phi_2}{B} \text{ where } B = 0.43 \text{ cm.}$$

and

$$\phi = 1.93 \times 1.0^{-5} (1 + 0.00012\, T) \left[2/3\, T^{3/2} - 248\, T^{1/2} + 2 \times 124^{3/2} \tan^{-1} \sqrt{\frac{T}{124}} \right]$$

In Fig. 3, ϕ has been plotted against temperature. Now it has been found that while B is independent of temperature of body T_1 it varies with T_2, and Dr. Langmuir has found for free convection it is proportional to it, *i. e.*

$$B_1 = B \times \frac{T_2}{T} \text{ where } B = 0.43 \text{ at 30 deg. cent.}$$

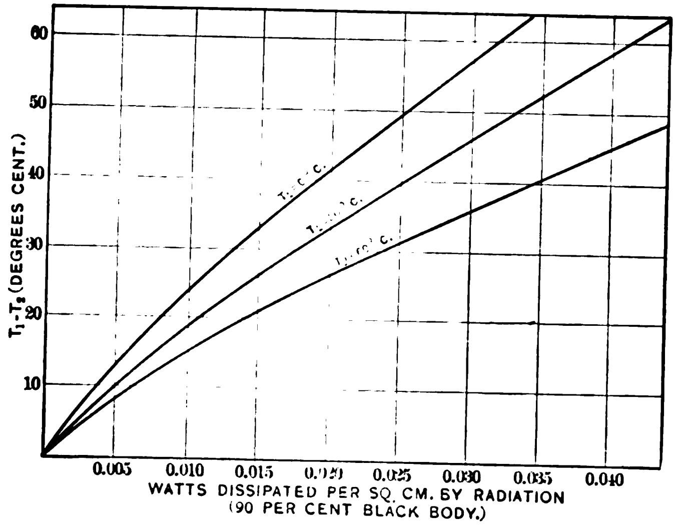

Fig. 2

Fig. 4 gives watts dissipated by convection for rises above various room temperatures. Unlike the dissipation by radiation, the energy dissipated by convection for a constant rise decreases with increasing room temperature, but to a much less extent, being almost independent of temperature.

In case of oil insulated apparatus, convection also comes into play in the transfer of heat from the coils or core to the surface of the enclosing case or cooling coils. The process is no doubt similar to that for air, consisting in a transfer of heat through the adhering film of oil by conduction, and then by convection currents to the case where a similar transfer takes place. The film of oil is probably subject to same changes due to velocity and temperature as is the air film. Further, with increasing temperature the viscosity of the oil will change considerably with a corresponding increase in velocity of convection currents. The net result of a higher room temperature on this step will be a more uniform distribution of temperature so that while the top oil will be cooler and the bottom oil hotter, the average mean temperature will be lowered. This is shown in Fig. 6, while in Fig. 5 are given curves showing changes in viscosity with temperature of some transformer oils.

In connection with the effect of oil on temperature rise of apparatus it should also be noted that with increasing temperature the volume of oil and the wetted surface is increased. The linear expansion of transil oil may be expressed by

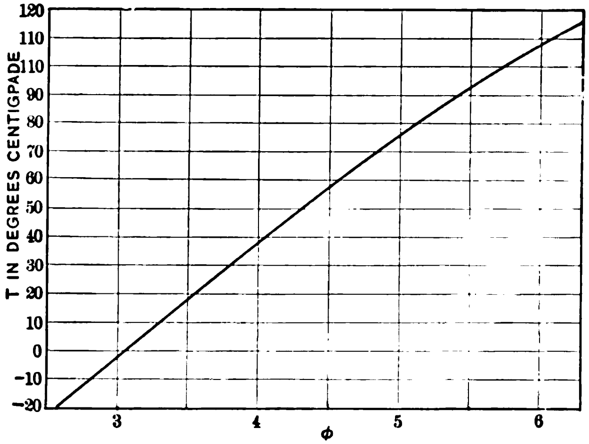

FIG. 3

$$\phi \times 100 = 4.19 \times 4.6 \times 10^{-4} (1 + 0.00012T) \times \left(\frac{3}{2} T^{3/2} - 248T^{1/2} + 2760 \tan^{-1} \sqrt{\frac{T}{C}}\right)$$

$V_T = V_0 (1 + 0.000895\ T)$
When V_T = Volume at temperature T
V_0 = Volume at deg. cent.
T = Temperature in deg. cent.

c. *On Conduction.* From equation (**3**) we had

$$Wd = \frac{K\ (T_1 - T_2)}{l}\ A\ t$$

The transfer is inversely proportional to the resistance to the passage of heat.

Copper has practically no temperature coefficient for conduction while the coefficient for iron is 0.00075.

Of the insulations, the conductivity of mica is unaffected by changes in temperature, while fibrous and cellulous materials such as are frequently used for turn and coil insulation, have a very considerable temperature coefficient, the thermal resistance being about 25 per cent less at 100 deg. cent. than at 0 deg. cent.

The effect of room temperature on conduction will in any case be small but will always tend to decrease the resistance of this step with increasing temperature of room.

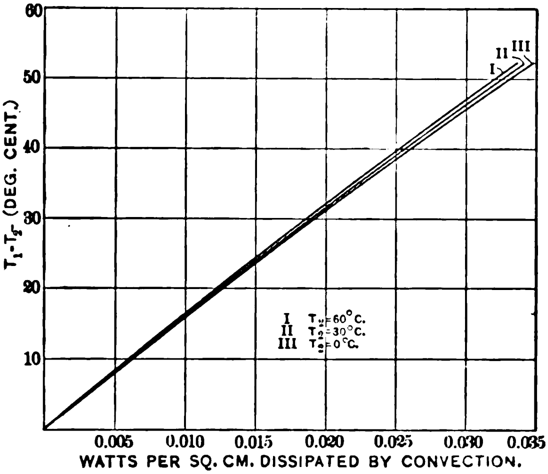

FIG. 4

The net effect of changes of room temperature on the dissipation of heat energy from stationary induction apparatus are

a. Effective radiation is greater the higher the room temperature.

b. The dissipation by convection in air is practically independent of room temperature. The transfer of heat by the convection currents in oil immersed transformers will however be somewhat increased with higher room temperature.

c. Conduction will be better at higher room temperature.

CONSTANT LOSSES

For a constant loss we would expect therefore that apparatus would operate at a lower temperature rise the higher the temperature of the surrounding air. The actual change in rise will of course depend upon the proportion of losses dissipated by radiation and convection. In the case of dissipation from tank surfaces this proportion varies greatly with different styles of

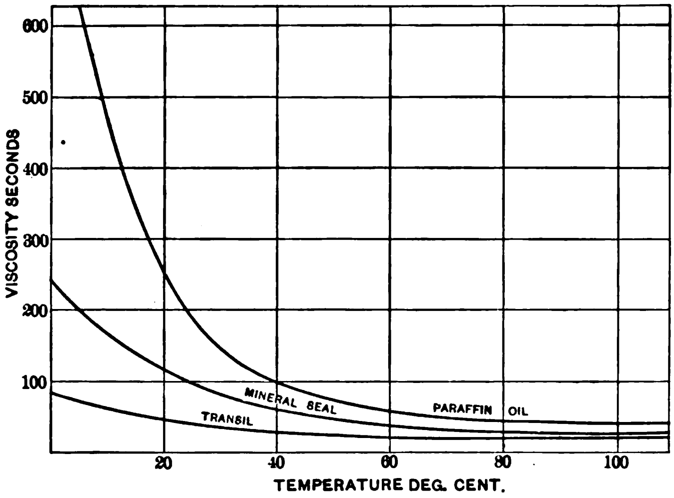

FIG. 5

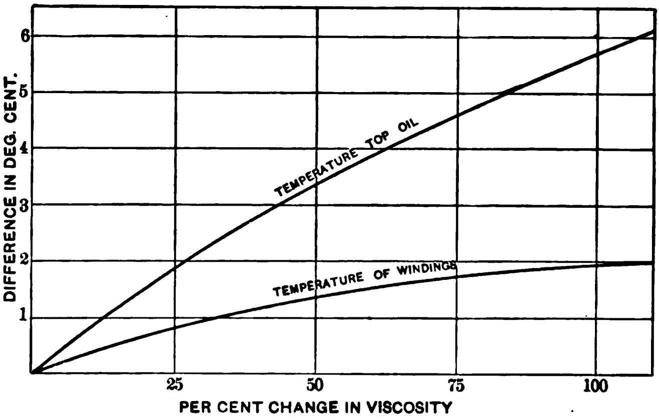

FIG. 6

tanks. The radiation value will be greatest on plain tanks, decreasing as the surface becomes more complicated by ribs, corrugations, flues, pipes, radiators, etc., the addition of which tend only to increase the convection component if the external dimensions remain the same.

In order to apply any correction to the emissive constants it is necessary to segregate the values for radiation and convection and apply to each separately.

Fig. 7 gives watts dissipated by various styles of tanks per square inch surface at 0 deg. cent. and 60 deg. cent. the percentage dissipation by radiation varying from 40 per cent to 16.6 per cent at 25 deg. cent.

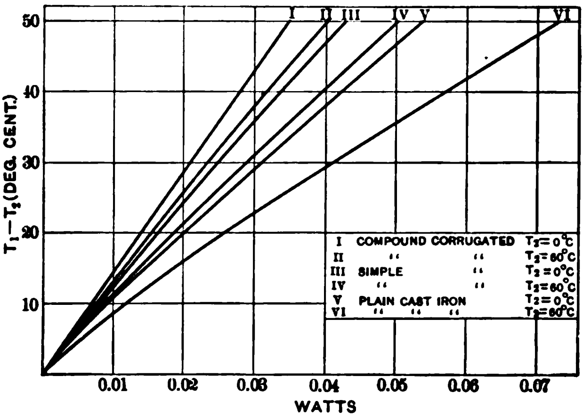

FIG. 7.—TOTAL WATTS DISSIPATED PER SQ. CM. (90 PER CENT. RADIATION + 100 PER CENT. CONVECTION.)

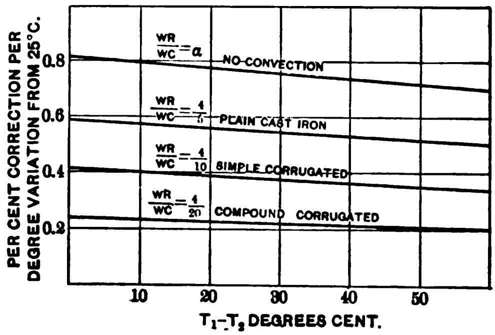

FIG. 8.—TANK DISSIPATION

Corrections to be applied in reducing observed rises to room temperature of 25 deg. cent.—Constant losses.

When $T_2 < 25$ deg. cent. subtract correction.

When $T_2 > 25$ deg. cent. add correction.

Fig. 8 gives correction for temperature for constant losses for same tanks to reduce to a standard reference of 25 deg. cent. room.

INCREASING LOSSES

While the core loss is practically independent of the temperature, the load losses ($I^2 R$) will increase with the temperature due to the temperature coefficient of copper. This difference in $I^2 R$ amounts to 0.0042 per cent for each degree variation and allowance must be made for this increase in losses in determining temperature rise at high room temperatures together with the increased effectiveness of the emissive constants.

Fig. 9 gives the correction for room temperature for various proportions of $I^2 R$ also for different proportions of radiation and convection.

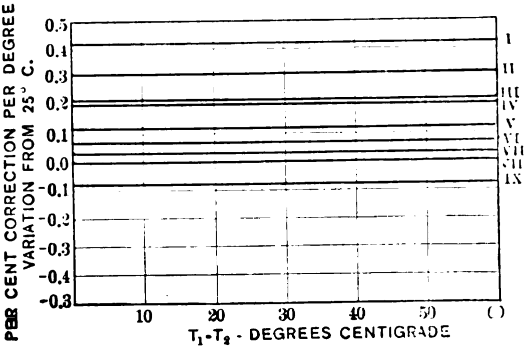

FIG. 9.—TANK DISSIPATION.

Corrections to be applied in reducing observed rises to room temperature of 25 deg. cent.—Increasing losses with temperature.

When $T_2 < 25$ deg. cent. subtract correction.
When $T_2 > 25$ deg. cent. add correction.

I—Plain cast iron. I^2R: core loss = 1 :2
II— " " " " " = 1 :1
III— " " " " " = 2 :1
IV—Simple corrugation. " " = 1 :2
V— " " " " " = 1 :2
VI— " " " " " = 2 :1
VII—Compound " " " " = 1 :2
VIII— " " " " " = 1 :1
IX " " " " " = 2 :1

WATER-COOLED APPARATUS

This type of apparatus depends on the dissipation of heat by two factors either of which may vary greatly in temperature. While the greater part of the heat is carried away by convection by cooling water the dissipation from the tank may have a considerable influence of the temperature rise of such apparatus as the table below shows.

It is possible in the case of this class of apparatus, under certain condition of temperature of room and ingoing water to have the tank absorbing heat from the air while under test and contributing to a higher rise of the apparatus.

The surface of the cooling coils will usually approximate to that of the tank in area but effectiveness of the cooling water is much superior to the air. Following is a table of rises with different temperatures of ingoing water and air temperature:

Loss watts	Surface		Temperatures deg. cent.			Watts tank	Radiated c.c.	Oil rises above *c*		
	Tank	c.c.	In Water	Air	Idler			In Water	Air	Idler
5000	10000	10000	25	25	25	900	4100	16^0	16^0	16^0
"	"	"	25	0	8	2700	2300	13^0	13^0	30^0
"	"	"	0	25	17	—400*	5400	18^0	-7^0	1^0
"	"	"	0	50	33	—1800*	6800	20^0	-30^0	-13^0
"	"	"	50	0	18^0	4600	400	10^0	60^0	42^0

*Heat absorbed by tank.

The radiating surface of the tank is greater than that of the cooling coils on the smaller units (up to say 1000 kw.), while on the larger sizes it is much less so that the influence of room temperature will not be felt so much.

Changing from one temperature to another of ingoing water will introduce very little difference in rise (providing the air temperature is same as ingoing water) since the specific heat of water increases only slightly with temperature and the increased effectiveness of radiation of tank with temperature may be neglected.

EFFECT OF BAROMETRIC CHANGES ON DISSIPATION OF HEAT

a. *Radiation.* Since changes in pressure are unaccompanied by any change in the diathermancy of the surrounding medium the heat dissipated by radiation will be unaffected by changes in pressure.

b. *Convection.* It has been found that for constant room temperature, the energy dissipated by convection is proportional to B (thickness of film).

For free convection Dr. Langmuir's experiments show that the thickness of the adhering film varies with the 0.75th power of the pressure while for forced convection this value was somewhat less. Using 90 per cent radiation value the writers found the value for free convection to be somewhat less than this, being about the 0.64th power (free convection).

Fig. 10 gives watts dissipated by convection plotted against pressure for a 40 deg. rise at 25 deg. cent. using constant 0.75.

c. *Conduction.* This will be unaffected by changes in pressure.

The net result of a change in pressure of surrounding air on dissipation of energy from a heated body will be that with increased pressure a less rise will be experienced with constant losses.

The difference in rise with different pressures will of course depend, as it did in case of room temperature, on the proportion of the emissive constants. Thus apparatus having smooth contours where the proportion of heat dissipated by radiation is a maximum, will be least affected by changes in pressure while those with complicated contours will have a large correction for pressure.

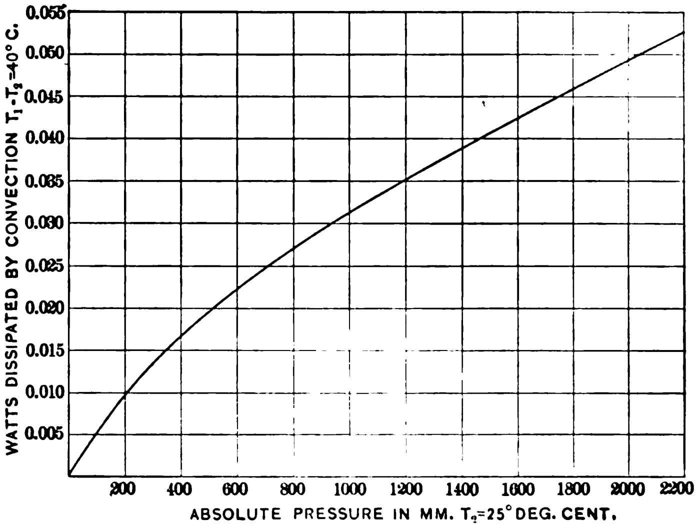

Fig. 10

The correction for room temperature will also vary with pressure, increasing with decreasing pressure. It is not possible to apply the same correction factor for room temperature at different atmosphere pressures.

Air-Blast Apparatus

In this type of apparatus, the cooling of both core and coils is accomplished almost entirely by convection, the heat being carried away by the convection currents caused by the blast. Very little heat will be dissipated by radiation from the windings, their insulation covering being at best a poor radiator, while the windings are generally so placed that what heat is radiated by one surface is absorbed by the next and vice versa.

Air-blast apparatus is either rated for operation at a certain air pressure or with a certain volume passing through the coils per minute.

Where the rating is based on volume of air it is evident that the weight of air per cubic foot increases with the atmospheric pressure, decreases with the temperature and is practically independent of the quantity of moisture (except where fog laden air is used). Since all the heat must be carried off by convection, it is evident that with increasing altitude or increasing temperature, the rise will increase for a constant volume of air passing through the ducts. The per cent increase being proportional to the temperature and inversely proportional to the pressure. It is probable that as in the case for free convection the correction for forced convection will vary more nearly as the 0.75th power which Dr. Langmuir found.

When the rating is based on air pressure, since the viscosity does not change with pressure, the same volume of air will pass through for the same difference in pressure, and correction will be the same as (1). The viscosity changes with the temperature however, so that for the same pressure the volume will change with temperature while the specific heat will also change slightly with temperature. It should be expected therefore, that since the viscosity varies as $T^{\frac{1}{2}}$ (approximately) and the weight as T^{-1} the weight per second would vary as $T^{-\frac{1}{2}}$ neglected change in specific heat.

Fig. 11 gives corrections to be applied to the observed readings for variations in atmospheric pressure (constant temperature) for free and forced convection.

Fig. 12 gives correction to be applied to observed readings for variation in atmospheric temperature (constant losses) for forced convection.

EFFECT OF HUMIDITY CHARGES ON HEAT DISSIPATION

Radiation. Since water vapor is not perfectly diathermus, radiation from a heated body will be affected by its presence in the atmosphere surrounding the body.

While there is practically no absorption in dry air, the presence of water vapor does increase the absorption somewhat.

Investigators differ greatly in their estimates of the absorption of water vapor and its effect on radiation. While the heat absorbed by the vapor will increase the temperature of the air a small amount, it is evident that the effect on radiation will in any case be small below saturation.

Convection. The presence of water vapor in the atmosphere will affect the quantity of energy dissipated by convection in so much as it affects the conductivity of the adhering film. We would expect, therefore, since the specific heat of water vapor is greater than dry air, the conduction of the film "*B*" would be increased, and the effectiveness of dissipation by convection increased.

An inspection of table III shows that for ordinary temperatures and barometric pressures, even up to the saturation value, the percentage of moisture compared to air (by weight) is very small amounting at most to a few per cent so that it can have very little effect on the convection value. The values as obtained by experiments seem to verify this, the difference in rises with varying percentage of moisture being entirely negligible.

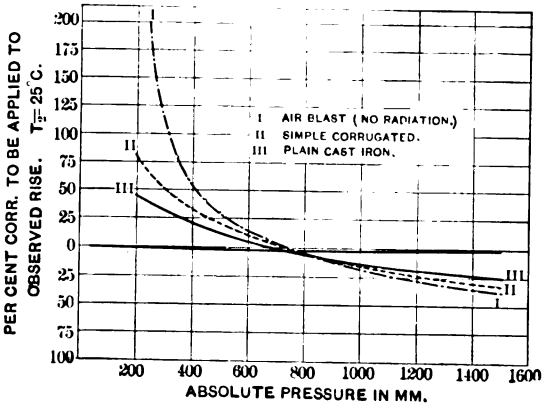

FIG. 11

In the case of fog laden air where particles of water are actually present, the case is very different, and a very considerable correction would have to be made.

EXPERIMENTAL OBSERVATIONS

Tests were made on two duplicate standard lighting transformers (oil-insulated, self-cooled), with losses within ½ of 1 per cent of each other. It was necessary to increase the losses above normal so as to obtain a 40 deg. rise by oil. This increase in losses was accomplished by holding over-load current, but normal excitation.

Heat tests were conducted in large pressure tanks, one transformer being placed in each tank, as shown in Fig. 16. The transformers were placed on wooden tables resting on the bottom of the tanks, the tops of the tables being nearly same area as base of transformer cases. Tanks were supplied with radiating coils connected to a steam and water source. An insulating asbestos shield was placed over the cooling coils so as to protect the transformers from their direct radiation.

Both tanks were provided with chloride driers through which air could be introduced under a pressure. In addition, vacuum connection could also be made.

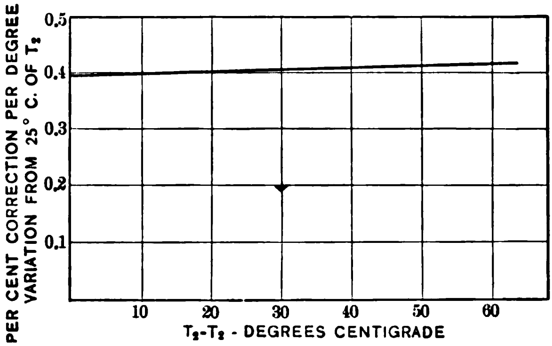

FIG. 12.—CORRECTION FOR AIR-BLAST APPARATUS ONLY—ASSUMING CONSTANT LOSSES.

When $T_2 > 25$ deg. cent. add correction.
When $T_2 < 25$ deg. cent. subtract correction.

The system of switching was so arranged that when the heat run was interrupted resistance measurements could be quickly taken.

Temperatures were taken by means of generator bulb thermometers read directly from a central dial while run was on. The thermometers were placed as in Fig. 16, check thermometers being used at the more important places. In addition, wet and dry bulb check readings were taken by spirit thermometers.

Very little heat was conducted from the transformer tank to the cover as a gasket of felt packing was placed between them. The temperature of the cover was very little above the surrounding air, so it was neglected in calculating radiating surface. Since the base rested on a wooden table, practically no heat was conducted from it. The total wetted surface at 25 deg. cent. was 6620 sq. cm. which corresponds to a radiating surface on outside of tank, 7020 sq. cm. The actual effective surface due to conduction to unwetted portion will be greater than this and in this case equal to 8500 sq, cm.

Further the temperature of the case was different at different heights being a maximum at top oil level, and decreasing toward top and bottom, the bottom temperature being less, the less the viscosity of the oil. To reduce to effective temperature for the whole tank it would be necessary to integrate from top to bottom.

TABLE I

Watts loss	Press. in mm.	P — 0.378 E in mm.	Grains H_2O per litre	Temp. deg. cent.		Rise deg. cent. top oil
				Air	Top oil	
422	236	216	0.342	27.5	78.0	50.5
437	235	208	0.703	59.0	99.2	40.2
423	475	470	0.264	30.0	76.0	46.0
436	477	470	2.11	59.5	98.0	38.5
422	740	737	0.194	24.5	71.4	41.9
435	735	733	0.362	45.0	86.3	41.3
440	734	731	0.622	61.0	96.0	35.0
420	1245	1233	0.292	26.0	66.0	40.0
435	1244	1231	0.565	61.0	93.0	32.0
413	1780	1772	0.256	26.5	63.0	36.5
435	1778	1770	1.44	59.5	91.5	32.0

In the present case, we have taken average temperatures which will probably be sufficiently close.

TEST OBSERVATIONS

I. *Readings taken to Determine Effect of Temperature of Surrounding Air.* Corrections made in pressure readings for elastic vapor pressure E of the water vapor present according to

$$P = P_1 - 0.378\,E$$

P = Calculated pressure in mm.
P_1 = Observed " " "
E = Elastic vapor pressure in mm.

Fig. 13 gives curves of the above with values in table I, (neglecting humidity) plotted with observed values and also corrected for constant losses. As would be expected from the previous discussion, the correction is greatest where the convection value is least, that is, at low pressures.

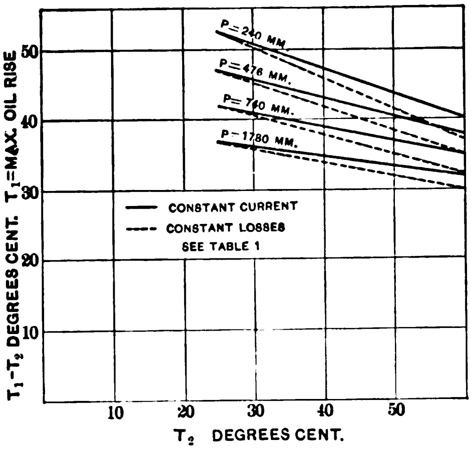

FIG. 13

II.—*Effect of Pressure.*

TABLE II A

Watts loss	Obs. press.	$P - 0.378\,E$	Grains H_2O per litre	Temp. deg. cent. Air	Temp. deg. cent. Oil	Rise deg. cent. oil
422	236	224	0.077	29.0	80.0	51.0
423	358	355	0.099	29.5	78.0	48.5
423	475	471	0.117	28.2	75.5	47.3
420	734	732	0.176	30.0	71.8	41.8
415	1252	1245	0.236	29.6	69.5	40.0
410	1780	1774	0.256	26.5	63.0	36.5
410	2280	2273	0.301	25.0	59.0	34.0

TABLE II B

438	236	210	0.705	59.0	99.2	40.2
437	476	470	2.08	59.5	98.0	38.5
435	731	731	0.622	61.0	96.0	35.0
433	1248	1237	0.565	61.0	93.0	32.0
432	1780	1774	1.44	59.5	91.5	32.0

Fig. 14 gives curves plotted temperature rise against pressure of room temperature for 30 and 60 deg. cent. room temperature.

Heat tests were also conducted on three 125-kw. self-cooled, oil-insulated transformers assembled in simple corrugated tanks at Schenectady, Pittsfield, Grand Junction, Colo., and Leadville, Colo., to determine what effect the altitude had on heating. Following is a summary of the tests made.

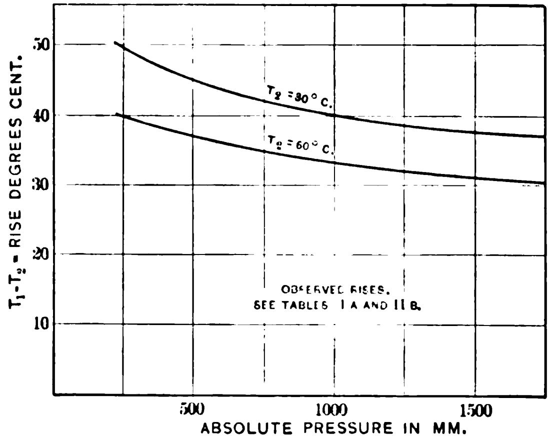

FIG. 14

TABLE II C

Place	Watts loss	P — 0.378 E	Grains H_2O per litre	Oil rise deg. cent.
Schenectady.....	4820	758	0.151	36.0
Pittsfield........	4820	732	0.116	37.5
Grand Junc......	3965	631	0.202	32.5
Leadville........	4570	518	0.197	39.6

Reduced to same loss the rises are given in Fig. 15 and Table II D.

TABLE II D

Place	Watt loss	P. 0.378 E	Grs. H_2O per litre	Oil rise deg. cent.
Schenectady........	4820	758	0.151	36.0
Pittsfield...........	4820	732	0.116	37.5
Grand Junction.....	4820	631	0.202	39.5
Leadville...........	4820	518	0.197	44.0

III. *Effect of Humidity.* Humidity measurements were taken by wet and dry bulb thermometers, the elastic force of the vapor being calculated according to formula.

$$E = E_1 - 0.00066\,P\,(t - t_1) \quad (1 + 0.00115\,(t - t_1)$$

where E = Vapor pressure in mm.
E_1 = " " of saturated aqueous vapor.
P = Pressure in mm.
t = Temperature of dry bulb (deg. cent.)
t_1 = " " wet " (deg. cent.)

Weight of one litre of dry air at 0 deg. cent. was taken as 19.52 grains. Correction for vapor pressure was applied to observed pressures according to the formula.

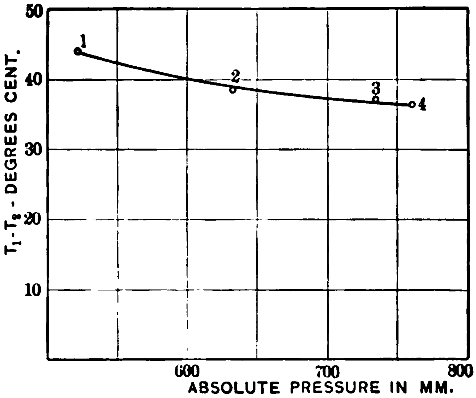

FIG. 15

Altitudes.

1.	Leadville, Colo.	3190 m.
2.	Grand Junction, Colo.	1525 m.
3.	Pittsfield, Mass.	346 m.
4.	Schenectady, N. Y.	75 m.

Observed rises on 125-kw. transformer, reduced to constant losses.

$$P = P_1 - 0.378\,E$$

where P_1 = Observed pressure.
E = Elastic vapor pressure
P = Calculated pressure.

Weight of dry air in one litre of air was calculated from

$$W = \frac{P - 0.378\,E}{29.92} \times 19.52 \text{ grains}$$

Weight in grains of water present in one litre of air was calculated from

$$W_1 = \frac{62.3\times E}{29.92-E}\times\frac{P-0.378\,E}{P}\times 0.1952 \text{ grains}$$

TABLE III

Watts	Pressure	$P-0.378\ E$	Grs. H_2O litre	Grs. litre dry air	Per cent moisture by wt.	Temp air.	Temp oil	Rise oil
422	236	234	0.078	5.65	1.3	29.0	80.0	51
"	"	232	0.156	5.62	2.6	27.5	78.5	51
"	"	216	0.342	5.50	6.2	27.5	78.0	50.5
422	358	353	0.100	9.70	0.99	29.5	78.0	48.5
"	"	352	0.123	9.70	1.31	28.0	76.5	48.5
422	475	471	0.087	12.15	0.715	27.0	74.5	47.5
"	477	473	0.117	"	0.965	28.2	75.5	47.3
"	477	473	0.202	12.10	1.67	27.0	74.0	47.0
"	476	472	0.204	"	2.19	30.0	76.5	46.5
420	735	733	0.162	19.0	0.86	30	71.3	41.3
"	736	734	0.176	"	0.93	30	71.8	41.8
418	734	733	0.187	"	0.98	28	69.3	41.3
420	734	734	0.190	"	1.01	30.5	71.8	41.3
"	737	736	0.197	"	1.04	29.5	71.4	41.9
"	735	733	0.265	"	1.40	30.0	72.0	41.5
417	1233	1231	0.194	32.1	0.55	27	66.0	39
"	1241	1236	0.236	"	0.74	26	66.0	40
418	1238	1235	0.292	"	0.91	29.5	69.5	40
414	1780	1776	0.256	44.8	0.57	26.5	63.0	36.5
413	1778	1774	0.278	"	0.62	24.0	60.0	36.0

CONCLUSIONS

Referring to Figs. 13 and 14 and Table III, it will be seen that the temperature rise of apparatus varies inversely with the temperature, inversely with the pressure and is practically independent of the water vapor over the ranges covered by test. The variations due to changes in amount of water vapor were small, and the results almost invariably showed the same rises for different quantities of water vapor present. This is to be expected, as a glance at Table III shows that even at saturation and moderate temperatures, the percentage of moisture is very small and can have little effect on the heat dissipation by convection or on the dissipation by radiation due to the change in diathermancy. With fog laden air *i. e.*, where particles of water are held in suspension the case is very different, the water now being a much greater proportion by weight of the mixture, the dissipation by convection being greatly increased while no doubt the dissipation by radiation will be some little diminished. The exact correction to be applied in any case will of course depend upon the proportion of heat dissipated by convection and radiation which in turn depends upon the type of apparatus and means of cooling.

RECOMMENDATIONS

It is evident from the above discussion that the corrections to be applied for variations in atmospheric conditions are not the same for different types of stationary induction apparatus, each type requiring special consideration.

Following the line of division given in the beginning of this paper it is recommended that the following corrections be made and precautions taken.

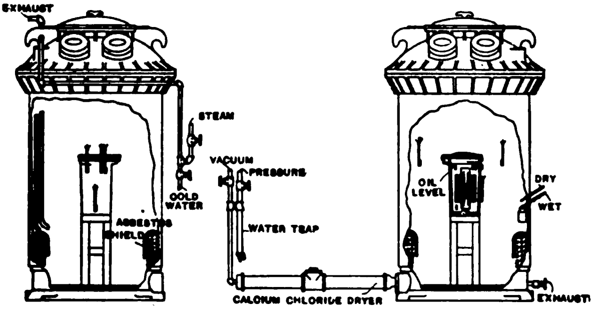

FIG. 16
(Both tanks are arranged alike.)

I *Corrections for variation in room temperature.*

(i) Air-cooled natural draft—no correction.

(ii) Self-cooled oil insulated—no correction.

(iii) Forced oil circulation—no correction.

(iv) Water-cooled apparatus—no correction but precaution should be taken to have the ingoing water at as nearly as possible the same temperature as the room which should be as near 25 deg. cent. as possible.

While in (i), (ii) and (iii) there will be a correction for variation in room temperature from standard, this correction will depend entirely upon the relative effectiveness of the emissive factors and in order to apply any such correction accurately it would be necessary to divide such apparatus into a large number of groups. It is safe to assume that the increased losses will about be compensated for by the increased effectiveness of dissipation and make no corrections whatever.

Of course wherever possible the apparatus should be tested under the same conditions as it is to operate or under conditions as nearly as possible approaching these.

(v) Air blast apparatus. A correction of ½ of one per cent per degree variation from 25 deg. cent. the correction to be added to the observed use when the reference temperature is below 25 deg. cent. (This correction is based on ratio of core loss to copper loss of 1:1 and on all the heat being dissipated by convection).

The reference temperature in this class of apparatus to be temperature of ingoing air where this differs from temperature of room in which apparatus is operating.

II *Correction for Variation in Atmospheric Pressure.*

(i) Air-cooled, one per cent correction for every 10 mm. variation from 760 mm. (This was obtained by assuming curve II Fig. 11, as a straight line between 400 mm. and 1000 mm.)

(ii) Same as (i)

(iii) (a) External air-cooled radiators—same as (i). (b) Water-cooling coils. No correction.

(iv) Water-cooled oil insulated. No correction.

(v) Air-blast apparatus. A correction of 2 per cent for every 10 mm. variation from 670 mm. (This was calculated from curve III Fig. 11, assuming as a straight line between 400 mm. and 1000 mm.)

III *Correction for humidity variations in atmosphere.*

(a) At and below saturation at ordinary room temperatures, no correction be made for moisture.

(b) When fog laden air is used the apparatus should be given a special rating, the specifications covering temperature rise when operating under such conditions.

NOTES ON INDUCTION MOTOR LOSSES

BY

R. W. DAVIS

Presented under the auspices of the

Standards Committee

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NOTES ON INDUCTION MOTOR LOSSES

BY R. W. DAVIS

ABSTRACT OF PAPER

The data obtained from numerous tests on induction motors, check the losses as given by the Standardization Rules with the exception of the fixed and stray losses. The tests show that both losses are less than would be obtained by the Institute method.

The true fixed loss should be taken as the power input, when the motor is running at rated voltage and without load, minus the stator copper loss produced by the magnetizing current. This copper loss is appreciable in slow speed motors.

With stator cores built up of well varnished punchings and without drifting or filing of the slots, the stray loss in the magnetic materials is negligible. The stray or eddy current loss in the stator copper is proportional to the stator copper loss, the percentage loss depending upon the degree of lamination of the conductor. The average stray loss of the test for both 25-and 60-cycle machines is approximately 6 per cent of the stator copper loss. The writer is not aware of any satisfactory commercial method of determining the stray loss in induction motor stators. It therefore seems desirable that an average value of the stray loss in per cent of the stator copper loss be adopted as standard.

In squirrel cage motors and small wound-rotor motors, where the slip is usually greater than 2 per cent, the total rotor loss should be determined from the slip reading when operating at full load. The rotor loss should be taken as the copper I^2r loss from resistance measurements in large wound-rotor motors where the slip of less than 2 per cent and a full load slip reading cannot be readily obtained.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26-28, 1913.

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(*Subject to final revision for the Transactions.*)

NOTES ON INDUCTION MOTOR LOSSES

BY R. W. DAVIS

The object of this paper is not a comprehensive treatment of the subject, but a few notes on the data obtained from numerous tests on induction motors. It is hoped that this and the other papers on the same subject will lead to further discussion and be of assistance in bringing about a revision of the Standardization Rules for the determination of fixed and stray losses in induction motors.

A large number of tests on motors of various sizes for 25- and 60-cycle circuits were compared and the data tabulated. The data obtained check the losses as given by the Standardization Rules, with the exception of the fixed and stray losses.

The power input to the motor when running at rated voltage and without load is taken by the Institute rules as the fixed loss: *i.e.*, friction, windage, core and copper losses which may exist in multiple circuit windings. This gives too large a figure, since it includes the stator copper loss due to the magnetizing current. This copper loss is quite appreciable in slow-speed motors. The true fixed loss should therefore be taken as the power input minus the stator copper loss produced by the magnetizing current.

The stray losses may be grouped under two general divisions: the losses in the stator, and those in the rotor. The writer is not aware of any satisfactory method of determining the stray losses in the stators of induction motors. An induction motor stator is very similar in construction to the stator of a definite pole alternator of corresponding rating, and tests on the latter apparently show that with properly built cores the stray loss in the magnetic circuits of definite pole alternators is negligible. The total measured loss checks very closely with the sum of the I^2r loss and the computed eddy current loss in the conductor.

Oscillograms showing the distribution of the flux in induction motor stators indicate that there is very little change in its distribution from no-load to full. It therefore seems to the writer that the stray losses in the magnetic materials of induction motor stators should be neglected. The data on stray loss in copper, given in the table, were computed by the same method which was found satisfactory for definite pole synchronous machines. These stray losses are expressed in per cent of the normal stator copper loss.

Horse power	Rev. per min. syn.	Volts	Cycles	Per cent stator stray loss	Full load slip		Locked losses		
					Test	Calc.	Stator	Rotor	Total stray
30	500	2200	25	*	3	2.4	41.2	23.5	35.3
40	750	440	25	5	4.2	3.5	44.3	38.2	17.5
75	720	440	60	1	3.3	3.5	48.1	33	18.9
100	500	2200	25	*	2.4	2.4	45	45	10
100	600	440	60	*	3.1	2.8	41.5	47.3	11.2
100	720	220	60	16	3.3	3.5	35.3	47	17.7
200	500	440	25	3	2.8	2.8	34.4	50	15.6
200	600	440	60	1	2.3	2.4	38	50	12
250	600	440	60	*	2.7	2.6	30.2	40.8	29
300	450	550	60	6	1.6	1.4	32.7	23.8	43.5
300	600	550	60	9	1.7	1.6	37.7	44.3	18
350	600	550	60	9	1.9	2	36	43.5	20.5
400	600	440	60	5	1.6	1.7	30.8	38.4	30.8
500	514	440	60	1	0.9	0.8	31	38	31
600	300	550	60	9	1.6	1.4	29	30.8	40.2
600	600	2200	60	2	1.3	1.2	29.2	35	35.8
800	750	6600	25	*	1.3	1.4	33	33	34
600	1200	2200	60	2	0.9	0.9	33.4	40.5	26.1

*Less than ½ per cent.

The stray losses in the rotor of an induction motor are a function of the rotor frequency and therefore produce slip. At standstill, full frequency is induced in the rotor, very greatly increasing the rotor iron loss and the eddy current loss in the conductor. The writer has taken advantage of this in designing squirrel-cage motors, obtaining good starting characteristics and low slip at full load with a resultant efficiency comparable with that of a wound-rotor motor. The present Institute rule for measuring stray losses includes these high losses at standstill as a part of the total loss in the motor at full load. The tests show that the slip at full load corresponds to the I^2r loss by resistance measurement and that the stray loss in the rotor at standstill is not present at full load in machines of small slip. The calculated slip given in the table is based upon the assumption that the only loss in the rotor is the copper I^2r loss determined from the resistance measurement. The test slip measured at full load is the average of a number of readings and checks the calculated slip within the limit of experimental error. The copper and stray losses in the table are taken from the lock test and expressed in per cent of the total loss on short-circuit. The tests are on wound-rotor motors, with the exception of the last, which is on a squirrel-cage machine with the bars bolted and soldered to the end rings, removing all poor contacts between bars and end rings.

Many of the tests checked were incomplete in some respect. Only those tests which were complete have been included in the table, although the date of all tests, in so far as they were considered reliable, were used in arriving at conclusions. Neglecting any small stray loss which may exist in the magnetic materials of the stator, the stator stray loss is proportional to the stator copper loss, the percentage loss depending upon the degree of lamination of the conductor and the frequency. The average stray loss in both 25- and 60-cycle machines is about six per cent of the stator copper loss. In rotors of small slip there is no stray loss shown within the limits of experimental error, and in rotors of large slip the stray loss under full load test is only a fraction of the rotor stray loss at standstill. The total rotor loss under full load is in every case less than the combined copper and stray losses obtained from the short-circuit test.

It therefore seems desirable that an average value of stator stray loss in per cent of stator copper loss be adopted as a standard. In squirrel-cage motors and small wound-rotor motors, where the slip is usually greater than two per cent, the total rotor loss should be determined from the slip reading when operating at full load. The rotor loss should be taken as the copper I^2r loss from resistance measurements in large wound-rotor motors where the slip is less than two per cent and a full load slip reading is not readily obtained.

BRUSH FRICTION AND CONTACT LOSSES

BY

H. F. T. ERBEN and A. H. FREEMAN

Presented under the auspices of the

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BRUSH FRICTION AND CONTACT LOSSES

BY H. F. T. ERBEN AND A. H. FREEMAN

Abstract of Paper

The paper calls attention to the insufficiency of the present Standardization Rules of the Institute on the subject of brush losses and their determination.

A more accurate method of determining the losses is described and rules are given for application of the data so obtained to the calculation of brush losses.

A recommendation is made for the amendment of the Institute rules to cover a more comprehensive and accurate method for the determination of such losses.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26–28, 1913.

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BRUSH FRICTION AND CONTACT LOSSES

BY H. F. T. ERBEN AND A. H. FREEMAN

The rapid development of modern electrical apparatus has necessitated most careful selection of brushes to meet the varying conditions of current, voltage, speed, etc., which in turn has required a very thorough study of their characteristics and losses.

The present Standardization Rules (Sections 103, 111, 112) fail to adequately cover this most important subject, and appreciating the necessity for more definite methods of determining brush losses, an exhaustive series of tests has been conducted during the past year, results of which are herewith presented.

The two sources of loss to be considered, either on commutators or on collectors, are brush friction and brush contact drop.

Friction. The friction of two bodies in sliding contact is governed by—1st, the nature of the materials, 2nd, the pressure forcing them together. The actual value of this friction (expressed in watts or h.p.) can only be determined by trial. Theoretically, the magnitude of the friction loss between two materials varies directly with the pressure and, therefore, the ratio of the force tending to retard the relative movement of the two bodies to the force pressing them together (coefficient of friction) should remain constant for all pressures less than that producing crushing or grinding of the materials.

Determination of Friction. To determine the coefficient of friction, a commutator was mounted on a shaft directly driven by an adjustable speed motor of such size that the maximum total load was less than the rated capacity of the motor. As many brushes as possible were assembled on the commutator in order that the brush friction might be a large part of the total load. Tests were made on numerous grades of brushes, in various types of brush holders, operating in both directions of rotation and through wide ranges of speed and pressure. The data thus obtained give the friction of brushes when carried in commercial brush holders. We are not yet prepared to give the full and complete results of these tests, as many of the results are now being verified. We show, however, on Curve 1 the coefficient of friction obtained at various speeds with one type of graphite brush operated at an angle of 37½ deg. leading. Fig. 1 shows what is meant by various angles, leading and trailing.

Test was also made to show the effect of temperature on coefficient of friction by enclosing a commutator in an asbestos-lined box, placing resistance grids under the commutator for a source of heat and piping a blower to the box to regulate and hold the temperature at various values. Tests were made at various speeds and at 40, 60, 75 and 100 deg. cent., and it was found that the change in input to motor over wide ranges in temperature was so slight as to be negligible in commercial applications.

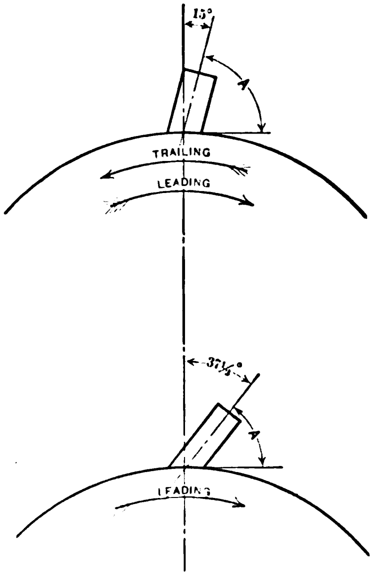


Fig. 1

We will later present similar curves showing coefficient of friction values with various types of brushes when operated at different angles.

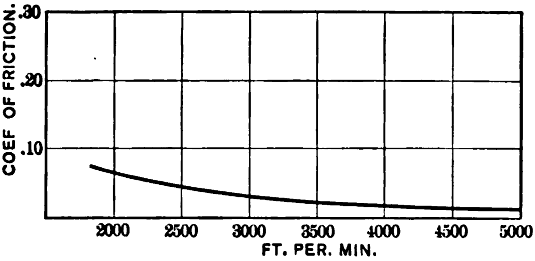
Application of Data on Brushes. Assuming the coefficient of friction as shown on curve to be applicable to the type of brush holder used, the friction should be calculated, as follows:

$$\frac{P \times S \times V \times F \times 746}{33{,}000} = W$$

When W = Watts loss, brush friction.
P = Total applied pressure on brushes.
V = Velocity, commutator or ring, in ft., per. min.
F = Coefficient of friction.
S = Sine of angle A (Fig. 1).

For example, on a commutator 25 in. (63.5 cm.) in diameter running 2500 ft. (763 m.) per minute with 60 grade S brushes at an applied pressure of 2 lb. (0.907 kg.) per brush operating at 37½ deg. angle.

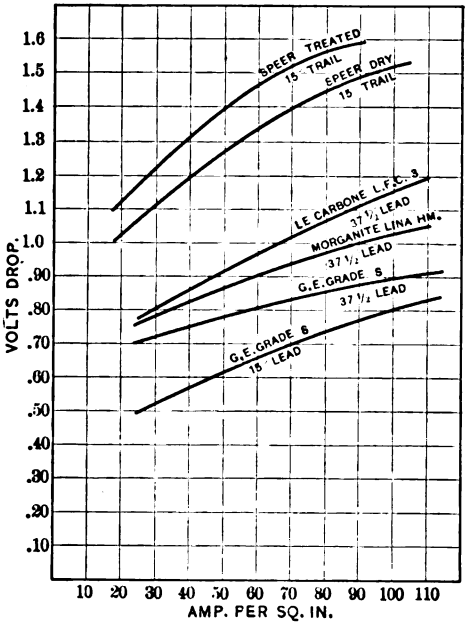
F = 0.05 (Curve 1).
S = 0.783.



Curve 1.—Coefficient of Friction, Grade S Brushes.
Angle 37½ deg. leading. Approx. 2 lb. per brush applied pressure.

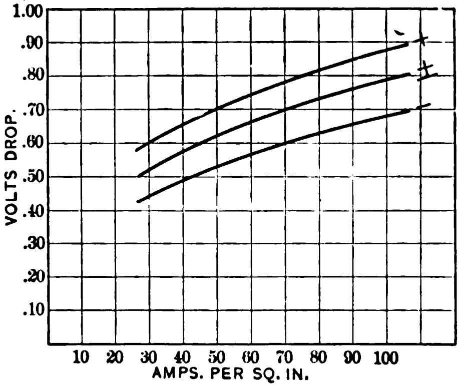
$$W = \frac{60 \times 2 \times 0.793 \times 2500 \times 0.05 \times 746}{33{,}000} = 270 \text{ watts}$$

Contact Resistance. Contact drop varies with the characteristics of the materials, with temperature, speed and pressure. Generally, the volts drop under the brush which is positive to the rotating element (negative brush on a d-c. generator) is greater than under the brush which is negative to commutator (positive brush on generator.) Curve 2 shows average volts drop with



CURVE 2.—BRUSH CONTACT DROP.—GROOVED COMMUTATOR.

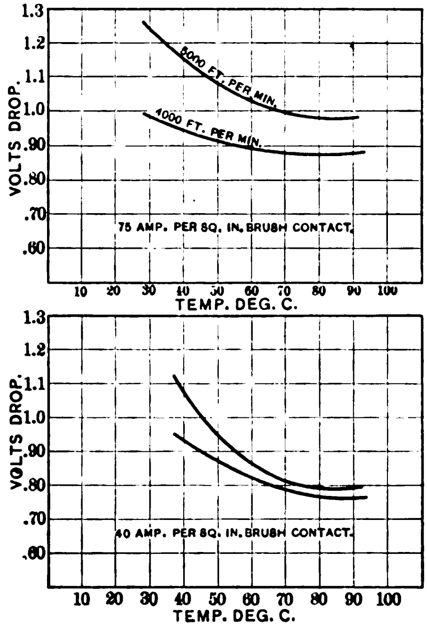
Average of positive and negative.
Average speed 2500 to 5000 ft. per min. Uniform spring pressure.



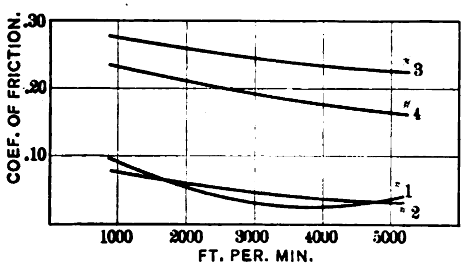
CURVE 3.—BRUSH CONTACT DROP.—GRADE *S* BRUSHES—GROOVED COMMUTATOR—65 DEG. CENT.

Average speed 2500 to 5000 ft. per min. 15 deg. lead.
+ = Current from brush to copper.
— = Current from copper to brush.

carbon and graphite brushes on grooved commutator. Curve 3 shows volts drop, positive and negative, and average between them. Curve 4 shows combined effect of temperature and speed



CURVE 4.—EFFECT OF TEMPERATURE AND SPEED ON BRUSH CONTACT DROP—GRAPHITE BRUSH, GROOVED COMMUTATOR.



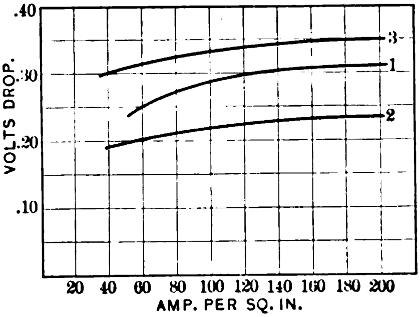
CURVE 5.—COEFFICIENT OF FRICTION, COPPER-GRAPHITE BRUSHES.

1—Metite grade *L*.
2—Lecarbone Metal, No. 2.
3— " *K K* 3.
4—Morganite *C M* 3.

on contact drop with graphite brushes. Curve 5 shows coefficient of friction of copper-graphite brushes such as metite, morganite CM-3, etc. Curve 6 shows contact drop with copper-graphite brushes or same grades. The data on contact drop shown on accompanying curves give the average of the drop under brushes of both polarities. The watts loss from contact resistance will then be

$$C\,V = W$$

in which W = Watts loss.
C = Current in amperes.
V = Total volts drop (twice volts drop shown on curve).



CURVE 6.—BRUSH CONTACT DROP—COPPER-GRAPHITE BRUSHES.
Average of positive and negative.
1—Metite, grade *L*.
2—Morganite *C M* 3.
3—Lecarbone *K K* 3.

SUMMARY

It is apparent from the foregoing that the niceties of adjustment found necessary in obtaining coefficient of friction show the hopelessness of determining the true friction loss by the method outlined in the existing Standardization Rules. It is evident that in measuring brush friction by reading the input to the machine with brushes up and brushes down there is a great element of error due to the fact that the value of brush friction is such a small percentage of the total input. It would, therefore, seem obvious that the Standardization Rules should be so amended as to allow the determination of brush losses by calculation from data which have been obtained by the most reliable methods and approved by the Institute.

WAVE FORM DISTORTIONS AND THEIR EFFECTS ON ELECTRICAL APPARATUS

BY

P. M. LINCOLN

Presented under the auspices of the

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WAVE FORM DISTORTION AND ITS EFFECTS ON ELECTRICAL APPARATUS

BY P. M. LINCOLN

ABSTRACT OF PAPER

The present rule of the Institute in regard to wave form is not satisfactory, as it does not sufficiently penalize the higher frequency harmonics. Deviation of the wave shape from the sine form is considered, and the effect on the current wave form in connection with various kinds of circuits, such as resistance, inductance and capacity. Conditions occurring with two differently shaped e. m. f. wave forms in parallel are also considered, and the resultant effect on the current wave. It is shown how, in some cases, very great current wave distortion may occur, or excessively large local currents may flow between synchronous machines, due to difference in e.m.f. wave shape. Several examples are given of excessive current and e.m.f. wave distortion. Errors in power factor meters and other instruments due to wave shape are discussed.

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WAVE FORM DISTORTIONS AND THEIR EFFECTS ON ELECTRICAL APPARATUS

BY P. M. LINCOLN

While the general question of wave shapes has given rise to comparatively little discussion among operating engineers, it has received considerable attention from those interested purely in the theoretical side of electric engineering. It has been in the past a question that has attracted the theoretical man and student rather than practical operating man. The reason for this is not far to seek. It lies in the fact that the average operating engineer has but a faint conception of what the shapes of his e.m.f. and current waves are really like. This lack of knowledge is due to two reasons: First, to the fact that there is no ready and inexpensive method of determining wave shapes. Determination of wave shapes requires the use either of an oscillograph or some point-by-point-contact method, either of which is rather expensive, and difficult of operation as compared to an ammeter, voltmeter, wattmeter, power factor meter, etc., that are every-day tools of the operating engineer. Second, and more important, this lack of knowledge of wave shapes on the part of the operating engineer is due to the fact that he rarely has had reasons to suspect that any of his troubles can be traced to wave shape, and whatever is free from trouble-breeding has but little direct interest to him. The only interest, therefore, that attracts the average operating engineer to the study of wave shapes is purely a scientific one, and as a rule this is not a sufficient incentive to cause him to spend the time and money that such a study would entail. The fundamental truth in the old saying " what we don't know, doesn't hurt us" is undoubtedly at the bottom of his indifference in this matter.

This indifference is more or less justified, since there are but few cases on record where distortion of wave forms has actually given rise to difficulties. It is, however, quite possible that wave shape distortion may cause serious trouble in electric circuits, and it is the object of this paper to discuss the question of wave form in some of the aspects that the operating engineer might be expected to meet in the discharge of his regular duties.

The sine form of wave has always been recognized as the standard. The reason for recognizing the sine rather than some other shape of wave as the standard, is sufficiently obvious and so well known as to need no discussion in this paper. Unfortunately, however, not all wave shapes are of the sine form. As is well known, any electrical wave, no matter how much distorted, may be viewed as being made up of a pure sine wave of fundamental frequency upon which are superposed other pure sine waves of a higher frequency, usually called harmonics. That is, any shape of wave may be taken as being made up of a multiplicity of pure sine shapes.

The origin of all the wave shapes which occur in any alternating-current system lies in the shape of the e.m.f. wave of the generators. The shape as determined by the generator may be modified by other synchronous apparatus, as will be indicated later in this paper.

The Standardization Rules of the Institute state that the generator e.m.f. waves shall not depart from the sine shape by more than 10 per cent. The present form of the rule is not entirely satisfactory, since it does not penalize the higher frequency harmonics as much as they deserve. A 10 per cent deviation on the part of one of the higher harmonics is admittedly more dangerous than the same deviation on the part of a lower harmonic, but the existing rule does not recognize this. A modification of the existing rule so as to obtain such a recognition is desirable.

Current waves, as a rule, deviate from the sine form much more than e.m.f. waves. There are various kinds of circuits through which the e.m.f. of a generator may cause a current to circulate. These may be classified as, first, pure resistance; second, pure inductance; third, pure capacity, and fourth, any combination of these three, either in shunt or in series. Arc lighting and rectifier circuits are not considered.

The influence of these various kinds of circuits on the current wave that is caused by a given form of e.m.f. wave will be as follows:

First, a pure resistance will have no effect whatever upon the current wave; that is, the shape of the current wave will be exactly the same as the e.m.f. wave which causes it.

Second, a pure inductance will tend to dampen out the higher harmonics in the current wave. If we have a pure inductance, therefore, we may expect that the current wave will be less distorted than the e.m.f. wave which causes it. The dampening out of the higher harmonics is in proportion to the value of the harmonics. For instance, the third harmonic in the e.m.f. wave will be reduced to one-third value in the resulting current wave, the fifth e.m.f. harmonic, to one-fifth in the current wave, the seventh, to one-seventh, etc. This result follows immediately from the consideration that the impedance offered by a pure inductance increases directly as the frequency.

Third, the effect of a capacity is exactly opposite to that of an inductance. It tends to exaggerate the harmonics in a current wave resulting from a given e.m.f. wave. Also the amount of the exaggeration is in exact proportion to the order of the harmonic. The third harmonic appears in the current wave as three times its value in the e.m.f. wave; the fifth harmonic, as five times, and the seventh harmonic, seven times, etc. For this reason the current waves that are taken by any condenser, such as, for instance, an empty transmission line, are as a rule very much distorted.

Fourth, a complex circuit consisting of any possible combination of the above simple circuits may have its current wave either smoothed out or exaggerated, depending upon the predominance of the particular kind of impedance contained. The unloaded transmission line is about the only kind of pure capacity that is met with in practical work. All other circuits are made up of resistance and inductance only. Further, in most operating circuits, inductive reactance predominates over resistance, so that there is a tendency to smooth out the current waves. This applies, of course, only to circuits with pure resistance and inductance, which is not the case when synchronous apparatus is in use, nor when saturation of iron circuits exists in the inductance, as, for instance, in transformer magnetizing currents.

The most important case, so far as distortion of wave forms is concerned, is in a circuit which contains synchronous apparatus, such as synchronous motors or converters, and such a circuit is not included in the foregoing classification. Circuits containing pure resistance, inductance or capacity, or complex circuits containing any combination of these, have no inherent wave form of their own; they receive whatever wave form is applied to them and their action in modifying the generator wave form, if any, is an indirect one. All synchronous apparatus, however, has a distinctive wave form of its own which may be very different from the generator wave form, and usually is at least slightly different. Not only is the shape of the current wave affected by the presence of synchronous apparatus, but also the e.m.f. waves of both the generator and the synchronous apparatus. The final wave form is the resultant of the action of all the synchronous apparatus on a given system.

Perhaps the best way of studying this matter is to assume a concrete case and study that case in detail. Let us assume, therefore, that we have a generating system that has a pure sine wave as indicated in curve A, Fig. 1. Let us assume, further, that we have operating on this system a synchronous motor that has a distorted wave form as shown in curve B. Fig. 1. In this case the distortion of wave B is made up by superposing a third harmonic of 10 per cent and a fifth harmonic of 10 per cent on a fundamental sine wave of 99 per cent. When harmonics are superposed on a fundamental the effective value of the resultant wave is the square root of the sum of the squares of the effective values of the various component sine waves. Thus the effective value of curve *B* is

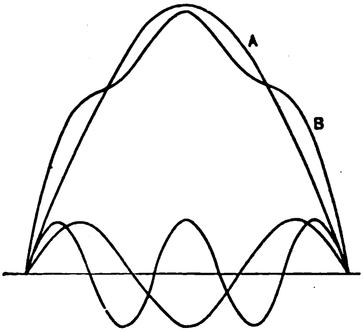

FIG. 1

$$\sqrt{(99)^2 + (10)^2 + (10)^2} = 100$$

The effective value of curve *B* is therefore exactly the same as *A*. Let us assume further that the synchronous motor with wave shape *B* has zero losses and that its field adjustment is such that its voltage before being synchronized is exactly the same as the supply circuit. If it were not for the difference in wave forms, these assumptions would result in no current flow in the motor, since it would oppose an e.m.f. exactly equal and opposite to the supply e.m.f. at every instant. However, with differing wave forms shown in Fig. 1, this is far from the case. Inspection will show at once that there are instantaneous e.m.fs. in the motor wave that are entirely unopposed by the e.m.f. of the generator wave. From our assumptions as to the amounts of wave form differences it follows that the value of the unopposed fundamental frequency is one per cent, and of the third and fifth harmonics 10 per cent each. If there is no deformation of either the generator or motor waves, the only thing that will oppose the flow of current due to these unopposed e.m.fs. will be the impedance of the circuit composed of generator armature, motor armature, leads, cables, etc. The inductive reactance of such a circuit is so large as compared with its resistance that the flow of current is governed by inductive reactance. Currents will therefore flow due to these e.m.fs. and the value of this current is directly in proportion to the amount of this differential e.m.f. and inversely proportional to its frequency. Suppose we assume further that normal voltage at fundamental frequency will cause fifteen times full-load current to flow in the motor armature and that the motor is small compared to the system upon which it operates. The differential e.m.fs. between curves *A* and *B* will then give rise to a fundamental frequency current of 15 per cent, a third harmonic current of 50 per cent and a fifth harmonic current of 30 per cent, or a total resultant current of over 60 per cent of full-load. Although the assumptions made would result in no current flow if the wave shapes were the same in motor and generator, the assumed difference in wave shapes gives rise to a circulating current of 60 per cent of full-load. Fig. 2 indicates the theoretical shape of the current wave resulting from these assumed conditions. It will be seen that the current wave is made more distorted than either of the voltage waves of which it is the resultant.

A source of considerable error in our theoretical calculations is the assumption of a constant fixed inductance in the armature circuits of both motor and generator. This assumption is not strictly true, since the inductance will vary to a considerable extent, depending on the angular position of the field.

The reluctance of the magnetic path for the flux set up by the armature current varies with the position of the field, sometimes the minimum air gap between pole face and armature is included in the magnetic path and sometimes the much larger gap of the interpolar space is included. This cyclic variation of reluctance may give rise to a still further distortion of the circulating currents.

In the foregoing it is assumed that the inherent wave forms of both motor and generator remain unaffected by the currents that circulate in their armature. This is far from being an admissible assumption. In the modern synchronous machines, full load current in the armature has some 50 per cent to 100 per cent of the magnetomotive force of normal field, that is, the field that gives normal voltage at no load. It is at once apparent, therefore, that the instantaneous values of the current that circulates in the armature of a synchronous machine has a very considerable influence over the magnetic flux at that instant and thereby over its wave form. For instance, look at the condition that is shown in Fig. 2. Here the effective value of the current is, as we have seen, 60 per cent of full-load and hence it has a value in setting up magnetic fluxes in the magnetic circuit of the synchronous motor equal to 30 per cent to 60 per cent of the normal field. The actual field strength at any instant is of course the resultant of all the magnetizing forces acting at that instant and hence the variation in field strength from instant to instant will be very considerable. The direction of this field form variation will of course be such as to oppose the flow of armature current which produces it.

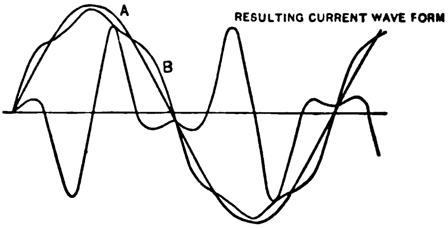

FIG. 2

Therefore the inductive reactance of the armature circuit is not the only influence that limits the flow of current due to differences in e.m.f. wave forms. The relative values of these two influences will depend to a large extent upon the construction of the field of motor or generator. As we have seen, superposed harmonics in the armature circuit will tend to cause rapid fluctuations in the magnetic fluxes of our motor. If the construction of the field is such that there is little opposition to these fluctuations, they will extend throughout the entire magnetic circuit. If, however, as is usually the case, the field structure is provided with " dampers," there will be currents set up in these dampers tending to oppose the fluctuation on the magnetic circuit. The net result of the harmonic in the armature current and the current that circulates in the dampers will be a " stationary wave " of magnetomotive force that will tend to superpose on the normal field form a harmonic flux of the same order of frequency as that in the armature current. This harmonic in the field flux produces a harmonic in the resulting e.m.f. wave, as has been ably shown by Professor C. A. Adams in various papers that he has presented before the Institute.

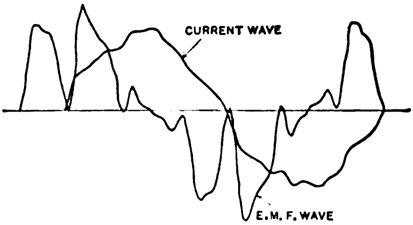

FIG. 3

A striking example of how an e.m.f. wave may be distorted by the effect of armature current recently came to the writer's attention. A 9000-kw. three-phase transformer was under test. The magnetizing current required amounted to some 500 or 600 kv-a. and the iron loss to some 60 or 70 kv. The test was being run from a 750-kv-a. generator. The behavior of the transformer, particularly in regard to noise, led to an investigation of the wave forms. Fig. 3 shows both the e.m.f. and current waves that were taken by the transformer. Fig. 4 shows the open-circuit e.m.f. wave form of the generator. It seems almost unbelievable that this amount of armature current could cause a distortion in the e.m.f. wave from that shown in Fig. 4 to that shown in Fig. 3, but this is an actual determination of wave forms, not a theoretical one.

This 750-kv-a. generator has nine slots per pole and its air gap is only about 40 per cent of the width of one slot. This condition gives rise to quite a noticeable tooth ripple. A careful analysis, however, shows that this wave contains comparatively small harmonics. The third and fifth are approximately two per cent each, and no other harmonic reaches a value of one per cent. The 17th, 19th and 21st vary from 0.6 to 0.95 per cent and apparently make up the ripple.

Subsequent tests on this transformer were carried out on a 5000-kv-a. generator with an open-circuit e.m.f. wave form as shown in Fig. 5. Both e.m.f. and current wave when exciting the 9000-kv-a. transformer are shown in Fig. 6. In this case the generator is so large that the exciting current for the 9000-kv-a. transformer causes practically no distortion.

In this connection, it may be well to call attention to a fundamental difference in the action of an a-c. generator as compared with a synchronous converter. This fundamental difference must necessarily result in circulating currents of higher harmonic frequencies. An a-c. generator, as we have seen, has a pronounced armature reaction. This armature reaction may be resolved into two components, one of which is demagnetizing to the degree that the generator carries wattless or inductive load, and the other cross-magnetizing to the degree that the generator carries true or real load. The demagnetizing component causes some field distortion and therefore wave form distortion, on account of the fact that the field form caused by the magnetizing action of the armature windings is of a different shape from that caused by the field windings. The cross-magnetizing effect, however, causes a much more marked distortion of the field form, since it causes a marked decrease in magnetic flux at one pole tip and a marked increase at the other. It is the cross-magnetizing effect, therefore, that causes the most pronounced field form distortion and, therefore, wave distortion. This cross-magnetizing effect is entirely absent

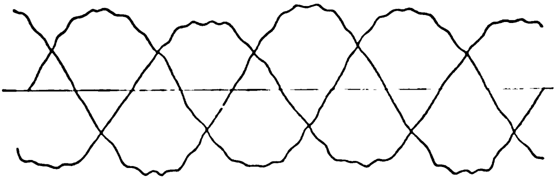

FIG. 4

in synchronous converters, and therefore their wave forms do not become modified due to true load in the same manner as a-c. generators. As the true load on an a-c. generator varies, its wave form may be distorted. There is no equivalent distortion of the wave forms of the synchronous converters with changes in their loads. It follows, therefore, that there must be some circulating currents of higher harmonics in order to compensate for this modification in generator wave form.

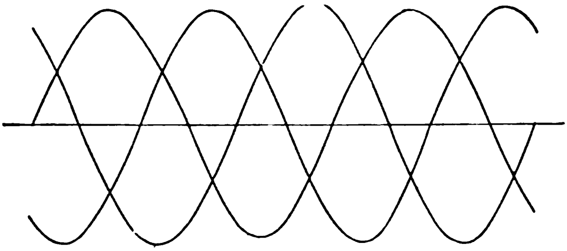

FIG. 5

It is the writer's opinion that the distortions of current waves, particularly in the currents that circulate between synchronous apparatus, are of greater magnitude than ordinarily supposed. It is evident that any distortion in the current wave is reflected to some extent in the e.m.f. wave. There is no particular harm resulting from these distortions except that the losses are somewhat increased.

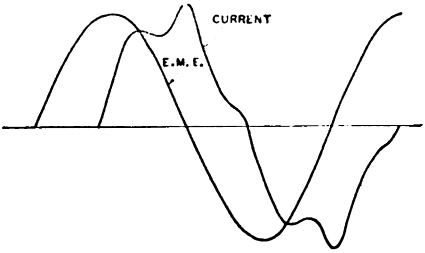

FIG. 6

The effect of superposed higher harmonics in current and voltage waves so far as the standard types of meters are concerned, deserves some discussion. The standard types of voltmeter, ammeters and wattmeters are not appreciably affected by wave form. This holds true no matter whether the actuating principle is magnetic attraction or heating. Each type integrates over the wave so as to obtain an indication depending on the r.m.s. or effective value.

Frequency meters of the vibrating reed type are unaffected, since they respond to the fundamental frequency only. The type that balances the pull of a current through a resistance against that of a current through an inductance is subject to a slight error, since the current due to the higher harmonics is partially suppressed by the inductance. The greatest error, however, may be expected in the power factor meter. The standard power factor meter is simply a device that measures the angle of lag or lead between a voltage and a current. A moment's consideration will show that this angle may be zero and still the power factor of the circuit be far from unity. Suppose, for instance, we consider the condition shown in Fig. 2. Here we have at no load a circulating current of 60 per cent of normal full load. Even if we had full load on the motor and adjusted the field so that a power factor meter showed 100 per cent, we would still have the 60 per cent current (or at least that part of it caused by the third and fifth harmonics—by far the larger part), shown in Fig. 2, superposed on the current that represents true energy. One-hundred per cent power factor is that condition where the kilovolt-amperes and the kilowatts are equal—have a ratio of unity—and it is manifest that this condition can never occur unless the e.m.f. and current waves not only have no angular displacement but also are of identical shapes. A power factor meter recognizes the angular displacement but does not recognize differences in wave shape. This is a matter that should be borne in mind when determining power factor with a power factor meter.

In conclusion, we may summarize as follows:

First, actual knowledge of the extent of wave form distortions existing on the average a-c. system is largely lacking. Second, with the exception of empty high-voltage transmission lines, the usual circuit that does not contain synchronous apparatus has a tendency to smooth out the harmonic in a current wave that is caused by a given e.m.f. wave.

Third, when two synchronous machines of different wave forms are operated on the same circuit, harmonics in the current waves are bound to appear and these currents have a marked tendency toward modifying the e.m.f. waves of all the synchronous apparatus through which they circulate.

Fourth, the indication of power factor meters cannot be taken at face value when harmonic currents flow.

LAWS OF HEAT TRANSMISSION IN ELECTRICAL MACHINERY

BY

IRVING LANGMUIR

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LAWS OF HEAT TRANSMISSION IN ELECTRICAL MACHINERY

BY IRVING LANGMUIR

ABSTRACT OF PAPER

In considering the effect of various conditions on the temperature rise in electrical apparatus, it is necessary to distinguish between the three modes of heat transmission; namely, conduction, radiation, and convection. The laws governing each of these factors are considered.

Conduction. A table of all available reliable data on heat conductivity of materials used in electrical apparatus is given. The effect of air spaces is considered. The temperature coefficient of the conductivity differs considerably for different classes of bodies. Methods are given for calculating the heat transmitted through bodies of various shapes.

Radiation. The Stefan Boltzman fourth power law is used to calculate the energy radiated from a " black body." A table for the relative emissivity of other bodies is given.

Convection. The laws of convection of heat from wires and plane surfaces at various temperatures are considered. The film theory of convection agrees well with experimental results and makes it possible easily to express the variation of convection with change of air temperature and pressure. For forced convection, Russell's equation gives reliable results. The effect of viscosity and other factors is of great importance in convection in liquids.

Combined Effects. Radiation and convection are usually about equally effective in carrying heat from a surface. The effect of these two factors can often be conveniently taken into account by assuming a certain surface resistance. It is very important to carefully distinguish between radiation and convection from surfaces when the walls of a room are at different temperature from the air contained in it.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, Fevruary 26-28, 1913.

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LAWS OF HEAT TRANSMISSION IN ELECTRICAL MACHINERY

BY IRVING LANGMUIR

Even in the simplest case of heat transmission, such as a laboratory measurement of heat conductivity, the phenomena involved usually prove to be quite complicated. It is in most cases nearly impossible to separate completely the effects of conduction, radiation and convection, and therefore if quantitative results are to be obtained, it becomes necessary to make an elaborate series of corrections, to eliminate the undesired factors.

In the case of the flow of heat from the interior of a piece of electrical apparatus to the exterior, the problem is necessarily much more complicated than in the simple experiment. Since each of the three factors, conduction, radiation, and convection are subject to totally different laws, the effect of any change in conditions can, in general, be determined only by considering what part each factor plays in the whole process and how each factor is affected by the new change in the conditions.

Failure to appreciate the necessity of separating each of these factors has rendered the majority of all investigations on heat transmission previous to 1880 almost valueless. Even today a very large number of published results on heat conductivity and surface emissivity are thoroughly unreliable from this cause.

It is surprising to what extent the old unreliable data maintain their place in present day hand-books and text-books. There is probably hardly a field in which so much care is needed in selecting proper sources for information the literature being full of absolutely contradictory statements. For example, one investigator concludes from his experiments that the total heat loss from small wires, heated to a given temperature, varies inversely proportional to the diameter, others state that it is directly proportional to the diameter, while still others find it to be independent of the diameter.

If electrical engineers are to seriously consider the question of heat transmission in electrical machinery, they must fully realize the great difference between the three modes of heat transmission and determine, first of all, what part each factor plays in each of the many types of machines.

In the present paper the writer has attempted to present in as clear a manner as possible the fundamental laws of conduction, radiation and convection of heat, and to furnish some experimental data which may seem to be of value to the electrical engineer.

CONDUCTION OF HEAT

The problem of the conduction of heat through solids was the first subject of mathematical and experimental study in the development of the theory of heat. Fourier and others developed the mathematical theory long before there was any reliable experimental data by which they could test their conclusions.

Fourier considered especially the problem of the rate of heating of a body capable of conducting heat. To solve this problem, he invented special mathematical methods which are now studied under the head of Fourier's Series. Because of the extreme complexity of this subject, mathematical analysis does not promise, for the present, to be of much value to the electrical engineer. We shall therefore limit ourselves to the simpler problem of the steady flow of heat which prevails after sufficient time has elapsed for the temperature through the apparatus to become constant.

For this case of steady heat flow through solids, the general law may be stated

$$W = \frac{A}{l}\mathbf{k}\,(T - T_0) \qquad \textbf{(1)}$$

where W = Watts of heat flow.
A = Area of cross-section of path of heat flow.
l = Length of heat path.
$\mathbf{k}$ = Coefficient of heat-conductivity expressed in watts per cm. per deg.
$T - T_0$ = Difference of temperature causing the heat flow.

Heat Conductivity of Solids. The heat conductivity, **k**, of solid bodies varies greatly for different substances, ranging from 4.2 watts per cm. per deg. cent. for pure silver to 0.0016 for such substances as rubber. The conductivity of finely divided solids, fibrous materials, powders, etc., is very much less than that of homogeneous solids. The best heat insulators known, such as eider-down, have a conductivity as low as 0.00020 watts per cm. per deg. cent.

Unfortunately, all the materials used for electric insulation are relatively poor heat conductors. Especially when the insulation contains air spaces, as in the case of braided coverings, the conductivity is very low.

In Table I the writer has collected together all of the *reliable* data he has, by careful search, been able to find on the conductivity of such materials as are of interest to the electrical engineer.

TABLE I.

Thermal Conductivities and Resistivities of Various Materials.

Materials	Temp. deg. cent.	Conductivity watts per cm. per deg. cent.	Resistivity	References
Metals				
Pure copper	18	3.84	0.260	2
Commercial copper	18	3.50	0.285	2
Pure iron	18	0.67	1.49	2
Steel 1 per cent C	18	0.45	2.22	2
Cast iron	100	0.40		
Transformer steel 4 per cent Si	20–250^0	0.32	3.12	1
Brass	"	1.30	0.77	1
German silver 30 per cent Ni	"	0.28	3.6	1
Constantan 60 Cu, 40 Ni	18	0.29	3.5	2
Calorite 65 Ni, 15 Fe 13 Cr, 7 Mn	20–250^0	0.16	6.2	1
Mineral Substances				
Graphite		3.57	0.28	11
Marble		0.030	33	3
Slate		0.020	50	3
Glass		0.011	90	4
Quartz glass		0.015	67	10
Porcelain		0.010	100	5
Insulating Materials				
Shellac		0.0025	400	4
Para rubber		0.0016	620	3
Gutta percha		0.0020	500	3
Paraffin		0.0026	390	3
Ebonite		0.0018	550	4
Paper		0.0013	770	3
Asbestos paper		0.0025	400	3
Varnished cotton tape		0.0027	370	6
Varnished cambric		0.0025	400	6
Mica paper		0.0016	630	6
Bakelite and linen tape		0.0027	370	6
Rubber tape		0.0043	230	6
Varnished cloth (empire cloth)		0.0025	400	7
Presspahn (untreated)		0.0017	590	7
Rope paper (untreated)		0.0012	830	7
Rope paper and oil		0.0014	710	7
Rope paper treated with varnish		0.0017	590	7
Fullerboard varnished		0.0014	710	7
Pure mica		0.0036	280	7

TABLE I.—*Continued.*

	Apparent density grams per. cu. cm.	Conductivity	Resistivity	References
Insulating Materials				
Built-up mica Micanite (19 per cent shellac)........................		0.0010	1000	7
Built-up mica Micanite 11 per cent shellac........................		0.0012	830	7
Linen tape varnished and baked.....		0.0015	670	7
Miscellaneous Materials				
Cotton Batting, loose..............	0.21	0.00046	2200	1
" " tightly packed.....	0.10	0.00030	3400	1
Pure woolen wadding, loose........	0.015	0.00049	2040	1
" " " packed slightly	0.054	0.00036	2800	1
Pure woolen wadding,tightly packed	0.192	0.00023	4400	1
Eider down, very loose............	0.0022	0.00045	2200	1
" " tightly packed....	0.077	0.00025	4100	1
" " " " "	0.11	0.00019	5200	1
Soft white pine ∣ to grain........		0.0016	640	
Liquids				
Water 25 deg. cent................		0.0057	176	4
Paraffin oil........................		0.0014	710	8
Glycerin 25 deg. cent..............		0.0024	410	4
Petroleum 23 deg. cent............		0.0016	630	8
Gases				
Air at 20 deg. cent.................		0.000249	4010	9
" " 100 deg. cent..............		0.000300	3330	9

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In the above table it will be noted that all the metals and alloys have a very high conductivity compared with that of non-metallic substances (with the exception of graphite). Practically all of the electrical insulators have a conductivity about one-thousandth of that of copper. The conductivities of various substances of any one type do not differ very greatly from one another; for example, the range of conductivities of organic materials used for electrical insulation is from about 0.0015 to 0.0040. The presence of air spaces in a body very much decreases the conductivity, as is seen for the extremely low conductivities of such materials as wool, cotton batting, etc. That this high thermal resistance is entirely due to the presence of gas, is evident from the fact that these materials are relatively good conductors when placed in an atmosphere of hydrogen.

In the case of powdered or fibrous materials, the heat conductivity is practically independent of the true conductivity of the solid substance forming the grains or fibres. For example, finely divided metallic powders, such as zinc dust or tungsten reduced by hydrogen from finely divided oxide, are extremely good heat insulators, although the material itself is a good heat conductor.

The conductivity of liquids is quite low, and is in most cases very insignificant compared with the amount of heat carried through the liquid by convection currents. The figures given above for liquids can be used only for liquids through which heat is being transmitted downwards, or in the case where the liquid is held in the meshes of some fibrous material such as cloth. This is a common case, however, in electrical insulation.

The heat conductivity of gases is smaller than that of solids and liquids.

Temperature Coefficient of Heat Conductivity. Pure metals, although they have a large temperature coefficient of electrical conductivity, have a thermal conductivity which is practically the same at all temperatures. Alloys have a conductivity which usually increases somewhat with the temperature, the temperature coefficient being never greater than about 0.1 per cent per degree cent., and usually much less than this. In electrical machinery, therefore, with the relatively small temperature range involved, we may consider the thermal conductivity as independent of the temperature.

In the case of pure crystalline, non-metallic substances, Eucken (*Ann. d Physik,* Vol. 34, p. 185, 1911) has shown that the thermal conductivity varies approximately inversely proportional to the absolute temperature. In other words, the temperature coefficient of such substances is usually about —0.33 per cent per deg. cent.

The same investigator has also shown that with amorphous, non-metallic substances, like glass the conductivity increases slightly with increase of temperature, the temperature coefficient being about +0.15 per cent per deg. cent. Such substances as paraffin, ebonite etc. are found to have practically no temperature coefficient.

Tests made by Mr. C. P. Randolph have shown that for powdered or fibrous materials the temperature coefficient of heat conductivity is very large. For example, measurements of the heat conductivity of Poplox at various temperatures up to 500 deg. cent. gave the results:

Range of temperature	Heat Conductivity Watts per cm. per deg. cent.
20 – 100	0.00030
100 – 200	0.00039
200 – 300	0.00057
300 – 400	0.00076
400 – 500	0.00133

This material (popped water glass) had an apparent density of 0.026 and contained air cells of about 0.5 mm. average diameter. The large temperature coefficient is caused by radiation across the walls of the air cells which is relatively large at high temperatures but almost negligible at room temperature. Below 100 deg. cent. the temperature coefficient for powdered and fibrous materials may be taken as + 0.3 per cent for materials with a coarse structure and proportionately less for finer structure.

In the case of gases, the mobility and the coefficient of thermal expansion are so great that convection becomes very large. It was thought for a long time that gases had no true conductivity. Maxwell, however, calculated the conductivity from the kinetic theory, and predicted that it would be independent of the pressure. His results have since been thoroughly verified. To avoid convection currents, it is only necessary to reduce the pressure of the gas to a value of several centimeters. At lower pressures the heat conductivity is found to be entirely independent of the pressure down to a pressure of one mm. When the pressure becomes much less than this, the free path of the molecules begins to become comparable with the length of the path along which the heat is conducted. At still lower pressures, the heat conductivity becomes proportional to the pressure. It is evident that the pressure at which the change from one of these laws to the other takes place is inversely proportional to the length of the path of heat flow. In the case, therefore, where we have the space subdivided by the presence of a fibrous material, we find that the heat conductivity does not remain constant down to such low pressures as one millimeter, but may even, with very finely divided materials, decrease with decreasing pressure, from atmospheric pressure down. This subject has been very fully treated by Smoluchowski [*Anz. Akad. Wiss. Krakau* (1910) A 129-153].

In the case of the heat conduction of gases, we find there is a large temperature coefficient of heat conductivity. It has been thoroughly proven that Sutherland's formula

$$\mathbf{k} = \frac{K \mathbf{c}_v \sqrt{T}}{1 + \dfrac{C}{T}} \tag{2}$$

very accurately represents the change in conductivity with the temperature. Here K is a constant, $\mathbf{c}_v$ is the specific heat of the gas at constant volume and c is a constant equal to 124 for air. In general, when $\mathbf{k}$ is a function of the temperature, we cannot use equation (**1**) to calculate the heat conduction through a given body. It can be shown, however, [Langmuir, *Phys. Rev.* Vol. 34, p. 406 (1912) ,] that if we substitute for the factor $\mathbf{k}\,(T - T_0)$ the integral $\int_{T_0}^{T} \mathbf{k}\, d\, T$ we are then able to calculate the heat conduction, no matter how much the heat conductivity may vary with the temperature. For such cases as these, the results can be calculated most easily by calculating or plotting the values of the integral $\int_{0}^{T} \mathbf{k}\, d\, T$. If we represent by ϕ the value of this integral, which we may call specific conduction, then the formula for heat conductivity becomes

$$W = \frac{A}{l} (\phi - \phi_0) \tag{3}$$

Heat Conduction Through Bodies of Various Shapes

Equations (**1**) or (**3**) can be used only for the heat conduction between parallel planes. In other cases, A and l are both variables, and the proper mean values must be determined, by special methods.

No matter what the shape of the body, the ratio $\frac{A}{l}$ has a definite value, if the surfaces of in-flow and out-flow of the heat are fixed. Let us call this quantity the "shape factor," and represent it by the letter s. Our equation for heat conduction thus becomes

$$W = s\,(\phi - \phi_0) \tag{4}$$

The value of the shape factor for bodies of various shapes may be of interest. In a paper to be published shortly (Langmuir, Adams, and Meikle, *Trans. Am. Electrochem. Soc.*, Vol. 23, 1913), methods for calculating the shape factor of bodies of many different shapes will be given. The following cases only are worthy of considering here:

Planes

$$s = \frac{A}{l}$$

Concentric Cylinders of diameters a and b.

$$s = \frac{2\pi}{ln \frac{b}{a}} \tag{5}$$

Concentric spheres of diameters a and b.

$$s = \frac{2\pi}{\frac{1}{a} - \frac{1}{b}} \tag{6}$$

Concentric Rectangular Prisms or Parallelopipedons. For this case, the following formula applies with great accuracy to the flow of heat where the thickness of the heat conducting material between the two surfaces is constant and where the thickness of the layer is not more than 2½ times the smallest dimension of the prism a condition nearly always fulfilled in practice. The formula is

$$s = \frac{A}{t} + \frac{1}{2}\Sigma l + 1.2\,t \tag{7}$$

Here t is the thickness of the layer of conducting material, Σl is the sum of the length of the 12 edges of the inner prism, and A is the total surface of the inner prism.

RADIATION OF HEAT

Dulong and Petit (1817) gave an empirical formula for heat radiation which has been used very largely by engineers almost up to the present date.

The Stephan-Boltzman law that the radiation from a black body is proportional to the fourth power of the absolute temperature has been shown to be derivable from the second law of thermodynamics, and has withstood the tests of very careful experimental investigation. We may therefore look upon this law as being one of the exact laws of nature. It must be remembered, however, that it applies only to radiation from a so-called black body; that is, a body which absorbs all heat rays which fall on it. Such a body can only be approximately realized, and any actual body must radiate less heat than an ideal black body at the same temperature.

The Stephan-Boltzman law, as applied to the radiation from any given body, may be written

$$\mathbf{W} = 5.7\,e\left[\left(\frac{T}{1000}\right)^4 - \left(\frac{T_0}{1000}\right)^4\right] \tag{8}$$

Here, **W** is the energy in watts radiated per square centimeter of surface. T is the temperature of the hot body, and T_0 the temperature of the surrounding space, e we may call the relative emissivity of the body; it is always a number less than unity and is a characteristic property of the radiating body.

The radiation constant, 5.7, is subject to some uncertainty at present. For several years, the commonly accepted value was 5.32, which was the result obtained by Kurlbaum (*Wied. Am.* 65, 746, 1898). Recently, however (1909), Féry obtained a value 6.3. Since then many investigators have redetermined this constant. Paschen and Gerlach (*Ann. d Physik*, Vol. 38, p. 30, 1912) obtained the value 5.9. Shakespeare (*Proc. of the Roy. Soc.*, Vol. 86A, p. 180, 1911) obtained 5.67. Within the next year or so the correct value of this constant will undoubtedly be determined. For the present, it would seem almost certain that the value 5.32 is too low, and that the value 5.7 must be fairly close to the true value.

The radiation of heat differs from conduction and also convection in that it is a purely surface phenomenon. The amount of heat radiated is strictly proportional to the extent of the surface, and is independent of the presence of gas adjacent to the surface. From bodies that are not black, the heat radiated from cavities in the bodies has a greater intensity than that radiated from a flat surface, for the reason that from such a cavity there is not only the heat radiated from the bottom of the cavity, but also that reflected by the bottom surface from the walls of the cavity. The above equation for radiation therefore applies only for heat that comes directly from a surface, and not for that which has been reflected from the surface. In general, however, this factor is not a difficult one to take into account in the consideration of heat radiation.

The most difficult question involved is the determination of the relative emissivity e. For clean polished surfaces of metals this quantity is small, ranging from 0.02 to 0.20. For non-metallic substances it is usually very much larger than this, ranging from about 0.3 up to about 0.9. The following table gives the values of e calculated by the writer from measurements made by C. P. Randolph. A detailed description of these measurements will be published in the *Trans.* of the Am. Electrochem. Soc., Vol. 23, 1913.

TABLE II.

Copper, oxidized by heating to a red heat	0.74
Copper, calorized; that is, surface impregnated with Al	0.27
Silver, pure, polished	0.03
Cast iron, fresh machined surface	0.25
Cast iron, oxidized by heating to red heat	0.65
Aluminum paint on cast iron	0.47
Gold enamel on cast iron	0.39
Monel metal, polished	0.40
Monel metal, oxidized	0.45

The relative emissivities from highly polished metal surfaces can be calculated from the reflectivity of the surface for heat rays, the emissivity and reflectivity being complementary to each other. That is the emissivity is equal to $1 - r$ where r is the reflectivity. There is a considerable amount of data in the literature on the reflectivities of metals for heat rays. However, it has been shown by Hagen and Rubens (*Ann. d Physik*, Vol. 8, p. 1, 1902) that the relative emissivity may be calculated by the formula

$$1 - r = e = 0.365 \sqrt{\frac{\theta}{\lambda}} \tag{9}$$

where θ is equal to the specific electrical resistivity in ohms centimeter units at the temperature of the metal and λ is equal to the wave length of the radiant energy in centimeters.

Recent investigations have shown that this formula is very accurate for wave lengths exceeding 0.005 mm. in length. The average wave length of the light corresponding to any given temperature is, according to Wien's radiation law, approximately $\frac{0.29}{T}$ cm. If we substitute this in the above equation, we obtain the value

$$e = 0.68 \sqrt{\theta T} \tag{10}$$

This equation enables us to calculate the relative emissivity for any highly polished metal up to about 500 or 600 deg. cent. However, because of surface oxidation, the emissivity will nearly always be much larger than this, except with such metals as silver, platinum, and gold.

Organic substances, such as oils, varnishes, resinous materials, have a very high emissivity; that is, between 0.8 and 1. Although in the visible spectrum these bodies are transparent, they are practically black bodies as regards the long heat rays that are involved in the radiation from bodies at ordinary temperature. The same is true of glass, this being practically a black body with respect to heat rays. Therefore, in calculating the amount of radiation from electrical insulating materials, we may very safely assume, whether these materials have a black color or a much lighter color, that they are nearly black bodies, as far as radiation is concerned.

The Temperature Coefficient of Radiation. For small differences of temperature, equation (**8**) may be written

$$\mathbf{W} = 0.0228\, e \left(\frac{T_0}{1000}\right)^3 (T - T_0) \tag{11}$$

We thus see that the amount of radiation between two bodies having a given difference of temperature, increases in proportion to the third power of absolute temperature. This means that the temperature coefficient of radiation between two bodies differing only slightly in temperature, is + 1.0 per cent per deg. cent. This is at least three times greater than the temperature coefficient of heat conduction through solids or even gases.

CONVECTION OF HEAT

The transmission of heat through liquids or gases takes place principally by means of currents set up in the fluid because of differences of density produced by the unequal heating. The amount of heat carried by convection depends on the velocity of the convection currents and also on the specific heat of the fluid. The currents are produced by the differences in density between the fluid in contact with a hot body and in contact with the cold body. This difference will be proportional to the coefficient of thermal expansion and also proportional to the density of the fluid itself. The currents produced by these differences of density have to act against the force of viscosity, thus the more viscous the fluid, the lower will be the velocity of the currents. We may therefore say, in a general way, that the amount of heat carried by convection will be roughly proportional to the product of specific heat, density, and expansion coefficient, and will be aproximately inversely proportional to the viscosity of the fluid.

From the very nature of convection, we would hardly expect it to obey such simple laws as those of radiation. It will depend upon the shape of the hot body, the distance between the hot body and the cold body, and upon each of the factors mentioned in the paragraph above.

There have been a great many investigations made of the laws of convection of heat, especially in gases. Dulong and Petit, in 1817, derived several empirical laws which have been more or less verified over rather narrow ranges of temperature by Péclet, (1860). These laws are today used in many engineering hand books as best representing the knowledge of convection of heat. Within the last thirty years, however, much more valuable work has been done, and we now know that the formulas of Dulong and Petit are only rough approximations.

Lorenz (*Ann. d Physik*, Vol. 13, p. 582, 1881) derived formulas for the convection of heat from vertical plane surfaces, making, however, certain rather arbitrary assumptions. He obtained the formula

$$\mathbf{W}_c = 0.548 \sqrt[4]{\frac{\mathbf{c}\, g\, \mathbf{k}^3}{\mathbf{h}\, H\, T}}\sqrt{\rho}\,(T_2 - T_1)^{5/4} \qquad (12)$$

where $\mathbf{W}_c$ = Heat convection per unit surface.
$\mathbf{c}$ = Specific heat of the gas at constant pressure.
$\mathbf{k}$ = Its thermal conductivity.
$\mathbf{h}$ = Its viscosity.
T = Its average temperature.
ρ = Its average density.
g = Gravitational constant.
T_2 = Temperature of plane surface.
T_1 = Temperature of the gas at a great distance from the plane.
H = Height of the plane.

Putting in the data for air, at room temperature, 27 deg. cent. and standard atmospheric pressure, this equation reduces to

$$\mathbf{W}_c = 0.000399\, H^{-\frac{1}{4}}\, (T_2 - T_1)^{5/4} \qquad \textbf{(13)}$$

where $\mathbf{W}_c$ is expressed in watts per sq. cm., and H is in cm.

This equation agrees well (within five per cent) with the results calculated by the writer from the experimental results of C. P. Randolph on the convection of heat from disks of metal 7½ in. (19 cm.) in diameter. It is very probable, from the method of derivation of this equation, that the influence of the height of the plane on convection is not as great as indicated by the term $H^{-\frac{1}{4}}$ in the equation.

Boussinesq (*Comptes Rendus*, 132, 1382, 1901) has treated the mathematical theory of free convection and obtained formulas similar in form to those of Dulong and Petit. In a later paper (*Comptes Rendus*, 133, 257, 1901) he develops the theory of forced convection from plane surfaces as well as from cylinders, spheres and ellipsoids. In all such calculations the simplifying assumptions that need to be made render it necessary to subject the formulas to very careful experimental test before much reliance can be placed upon them.

Compan [*Ann. Chim. phys.* (7) 26, 488 (1902)] has made elaborate experiments on free convection from a copper sphere two cm. in diameter placed in hollow concentric spheres of various sizes. He worked at pressures ranging from a few thousandths of a mm. up to six atmospheres. He varied the temperature of the small sphere from 300 deg. down to 50 deg. He found that over this whole range of temperature and for pressures above 20 cm., the convection varied with the 1.233 power of the temperature difference and with the 0.45 power of the pressure. The writer up to the present has not been able to procure more than an abstract of the report of this investigation, but will endeavor to collect this material into a form that will be useful in a study of heat transmission in electrical machinery, and will present it before this Institute.

Ayrton and Kilgour [*Phil. Trans.* 1892, abstract in *Proc.* Roy Soc. 50, 166 (1891)] have made elaborate investigations of the heat losses in air from very fine platinum wires [0.0012 to 0.014 inch (0.03 to 0.35 mm.) in diameter] at temperatures from room temperature up to 300 deg. cent. Their results were expressed in tables and empirical formulas only.

They found that the heat loss from the wires was nearly independent of the diameter of the wires.

Porter (*Phil. Mag.*, Vol. 39, p. 267, 1895) pointed out that this practical independence of the convection from the diameter of the wire may be accounted for by assuming that the heat is carried from the wire principally by conduction. He derives some equations with three empirical constants, which agree excellently with Ayrton and Kilgour's results. However, he obtained values for the radiation from the wire and for the conductivity of the air which were totally different from those which we now know to be the true values. His formulas must be looked upon, therefore, practically as empirical formulas.

A. Russell [*Phil. Mag.* 20, 591, (1910)] recalculated the results of Boussinesq (*loc. cit.*) and put them in a practical form. These are purely theoretical equations which give the heat lost by convection from cylinders and planes in currents of gases or liquids.

The writer (*Phys. Rev.*, Vol. 34, p. 401, 1912) showed that the free convection of heat from small wires consisted essentially of conduction through a film of gas of definite thickness. It was shown experimentally that the thickness of the film is independent of the temperature from 100 deg. cent. up to the melting-point of platinum. The thickness of this film depends on the diameter of the wire, but in such a way that it may be calculated with no other data than the diameter of the wire and the diameter which the gas film would have in the case of convection from a plane surface. To calculate the heat lost by convection from any wire, all that is required is to know the coefficient of heat conductivity of the gas and the thickness of this gas film for a plane surface, this latter being a constant quantity characteristic for a gas at any given temperature and pressure.

It was shown [Langmuir, PROCEEDINGS, A. I. E. E., 31, 1011 (1912)] that the formulas derived from this film theory agreed excellently with the experimental data of Kennelly (TRANSACTIONS A. I. E. E., Vol. 28, p. 363, 1909) on the convection of heat from small copper wires in air at various pressures and in air moving at different velocities.

In the following pages the writer has attempted to give the principal laws for the convection of heat under the different conditions which influence it.

Free Convection. The film theory of convection makes it possible to calculate the convection from plane surfaces, from cylinders or wires of any diameter, and from spheres.

In the case of plane surfaces, the heat lost by convection is calculated simply by considering that there is a layer of air 4.3 mm. thick, adhering to the surface, and through which the heat has to be carried by conduction. It must, of course, be remembered, that in addition to this heat loss by convection, there is the heat lost by radiation.

This film theory fully explains the fact that for wires of very small diameter the heat lost by convection is nearly independent of the diameter. This follows from the shape factor (see equation **5**) for concentric cylinders, since the logarithm of a number varies only slowly as the number increases.

The amount of convection from the surface differs only slightly whether the surface is placed vertically or horizontally. With a surface placed in the latter position, so that it is exposed to the air above it, the heat lost by convection is about 10 per cent. greater than when the surface is placed vertically. With the surface horizontal, but inverted so that it must lose its heat downward through the air, the heat lost by convection is naturally considerably less. For a 7½ in. (19 cm.) disk, placed in this position, the heat loss was actually found to be only 50 per cent of the heat lost when the surface is placed vertically.

The amount of convection from a surface probably does not depend, to any great extent, on the nature of the surface. At least, as far as the writer knows, there is no trustworthy experimental evidence that the surface has any influence.

It is a surprising fact that between the temperatures 100 and 500 deg. cent. the convection calculated from the film theory as above outlined, gives nearly identical results with those calculated by Lorenz' formula (see equation **12**). At temperatures above 500 deg. cent., both for convection from plane surfaces and from wires, the convection calculated from the film theory agrees better with the experimental facts than that calculated from Lorenz' formula. At temperatures much below 50 deg. the two formulas begin to diverge quite widely. The film theory would indicate that the convection would fall off practically linearly as the temperature difference decreases; whereas, according to Lorenz' equation, the temperature would be proportional to the 5/4th power of the temperature difference. This would mean that for very slight differences of temperatures—for example, 5 or 10 deg.—that Lorenz' equation would give very much lower results than would be obtained from the calculation from the film theory.

To decide which of these two theories would give the correct result for very small temperature differences, will require careful experimental investigation. Probably the bulk of the evidence at present is in favor of Lorenz' equation.

It should be pointed out that there is no theoretical reason known why the thickness of the film should remain constant, as the temperature of the wire or plane varies. This is simply an experimentally determined fact at temperatures above 100 deg. cent. It is quite possible that for very small temperature differences, the film thickness might become greater. In any case, however, the variation in the film thickness down to temperature differences as low as 30 deg., would not be very important in most calculations of heat convection.

Effect of Pressure on Free Convection. The heat conductivity of gases is independent of the pressure. According to the film theory, therefore, the effect of pressure on the amount of heat convection would depend simply upon the effect of pressure on the film thickness which we will call B. Theoretically, it would be very difficult to determine exactly what this effect would be. But it is certain that as the density of the gas decreases by the reduction of pressure, the thickness of the film B would increase; not necessarily inversely proportional to the pressure, however.

From Kennelly's data the writer found that B varied inversely proportional to the 0.75 power of the pressure. From some recent experiments with small wires in air, over a wide range of pressure, the writer finds that B varies more nearly inversely proportional to the first power of the pressure. From small wires however the amount of heat convection depends only slightly upon the diameter of the film. In these experiments therefore it is very difficult to find accurately the law according to which the film thickness varies with the pressure. As the size of the wire decreases, the convection becomes less and less sensitive to pressure changes.

For the effect of pressure on the convection from plane surfaces, there is only very meagre experimental data. Compan, in studying the convection from spheres 2 cm. in diameter, concludes that the convection varies with the 0.45 power of the pressure. According to Lorenz' equation, the amount of convection from plane surfaces would be proportional to the 0.5 power of the pressure. This would be equivalent to saying that B varies inversely proportional to the 0.5 power of the pressure.

To decide exactly how convection varies with pressure, we require further experimental work on plane surfaces in air at various pressures. Provisionally, it is probably safe to say that for the convection from plane surfaces or wires, the value of B is inversely proportional to the 0.5 power of the pressure.

Effect of Temperature on Free Convection. From experiments by the author on convection from platinum wires in air at various temperatures from − 180 up to 700 deg. cent., it would appear that the film thickness for a plane surface is approximately proportional to the absolute temperature.

The temperature coefficient of heat convection for small wires will simply depend on the temperature coefficient of the heat conductivity of the air, since in this case the amount of heat convection depends so slightly on the film thickness. From Sutherland's equation (**2**) it may be shown that in the neighborhood of room temperature, the heat conductivity of air increases approximately proportional to the 0.76 power of the absolute temperature. This would mean that the temperature coefficient of heat conductivity at room temperature is + 0.25 per cent per degree, and this would be the temperature coefficient of heat convection from the wire.

In other words, more energy would be required to maintain a wire at a given temperature elevation above its surroundings, the greater the temperature of the surroundings.

It is quite different with the convection of heat from plane surfaces. Here, the convection depends not only on the heat conductivity of the air, but also on the thickness of the film. Since the latter varies proportionally to the temperature, the amount of convection from plane surfaces will be proportional to

$$\frac{T^{0.76}}{T} = T^{-0.24}$$

In other words, the temperature coefficient of the heat convection will be − 0.08 per cent per deg. cent. From plane surfaces the convection with a given temperature difference decreases slightly with increasing air temperature.

Lorenz' equation would lead to the temperature coefficient of − 0.37 per cent per degree, for convection from plane surfaces.

Forced Convection. The effect of air currents on convection is very great, as is well known. However, the air currents that occur in an ordinary room, at some distance from the windows, have only very slight effect on the convection from wires and plane surfaces heated to several hundred degrees. By placing a few large screens around the body, very consistent results are obtained. With higher wind velocities, such as those obtained by placing an electric fan close to the body, the amount of convection, both from plane surfaces and from wires, increases about four-fold. Measurements with an anemometer showed the wind velocity in this case to be about 400 cm. per second.

Kennelly has investigated the effect of wind velocity on convection from small wires, and has found that the amount of convection varies approximately in proportion to the square root of the velocity. For velocities from 300 to 1800 cm. per second, he finds that the convection is proportional to the quantity

$$\sqrt{\frac{v + 25}{25}}$$

That is, the convection of any given wind velocity can be calculated from the velocity in quiet air by multiplying by the above factor. From some very rough experiments by the writer, on convection from plane surfaces and also from some calculations from published data (see article in *Trans.* Am. Electrochem. Soc., Vol. 23, 1913,) the amount of convection is again found to vary with the square root of the velocity, and the above factor is found to be

$$\sqrt{\frac{v + 33}{33}}.$$

Compan, in his experiments on spheres, finds that the convection varies with the square root of the velocity. Boussinesq has also arrived at the same conclusion from theoretical calculations.

From Kennelly's results, the writer drew the conclusion that the film thickness varied inversely as the 0.75 power of the velocity. This gave results agreeing well with Kennelly's data, but it has been found that the film thickness, in the case of forced convection from plane surfaces, is very different from that found for small wires in wind of the same velocity. This fact renders the film theory almost useless in cases of forced convection.

The best single equation for the calculation of convection of wires is probably an equation calculated by Russell *loc. cit.* by the method first given by Boussinesq. This equation is

$$\mathbf{W} = 8\sqrt{\frac{c\,\rho\,\mathbf{k}\,v\,a}{2\,\pi}}\,(T_2 - T_1) \qquad \mathbf{(14)}$$

where **W** = Convection loss per unit of length from the cylinder.
c = Specific heat of the gas or liquid at constant pressure.
ρ = Density of the fluid.
k = Heat conductivity.
v = Velocity.
a = Diameter of the cylinder.
$T_2 - T_1$ = Difference of temperature between the cylinder and the fluid.

If, in this equation, instead of the coefficient 8 in front of the radical sign, we place 5 or 6, we find that the results agree well with Kennelly's experimental data. On the other hand, for large cylinders from 2 to 10 cm. in diameter, the formula gives good results with the coefficient between 7 and 8.

In the case of forced convection in air at room temperature, equation (**14**) reduces to

$$\mathbf{W} = 0.000180\, C \sqrt{V a}\, (T_2 - T_1) \text{ watts per cm.} \qquad \mathbf{(15)}$$

where c is the number that varies from 5 to 8, according to the size of the wire as described above.

From equation (**14**) we can calculate that with a given difference of temperature and given wind velocity, the amount of convection would vary with

$$\sqrt{T^{-1+0.76}}$$

This would mean that forced convection under these conditions would have a temperature coefficient of − 0.04 per cent per degree; that is, with a given difference of temperature, the amount of convection would decrease slightly as the temperature of the air increases.

If the velocity of the air is produced by centrifugal force, as it often is in electric machinery, the velocity of the air currents will probably decrease as the air temperature increases, since the density decreases and the viscosity increases. The effect of this would be to make the temperature coefficient numerically still greater.

If the convection currents are caused by flue action, (for example, because of heat given to the air in long passages), this effect will be still more marked, so that the temperature coefficient will be strongly negative.

In problems on convection of heat, the flue action is often very important. For example, in studying the convection from a horizontal, plane disk, 7½ in. (19 cm.) in diameter, we find that if we place a cylinder of asbestos paper about 10 in. (25 cm.) in diameter and 6 in. (15 cm.) high, around the disk, the convection is nearly doubled when the disk is at about 150 deg. At higher temperatures the effect of the cylinder becomes relatively much less. By observing the motion of smoke in the air above the heated disk, it is seen that the air descends along one side of the cylinder, moves across the disk, and rapidly rises along the other side of the cylinder. In general, with vertical surfaces of considerable height, any means of preventing horizontal air currents from flowing in towards the middle portion of the surface, will tend to increase the convection, since it causes the air to be drawn over the lower portion of the surface with very much increased velocity. However, if such flues as are made in this way are too long, the convection again tends to decrease, since the air that comes in contact with the upper part of the surface is already heated by flowing along the lower part of the surface, and is therefore capable of taking up very little more additional heat.

The whole subject of flue action in convection is as yet very little understood, and should be the subject of further careful experimental investigation.

Convection in Liquids. The convection in liquids, in principle, at least, does not differ radically from that in gases. However, the velocity of the currents set up is very much less than in the case of gases, but because of the very great heat capacity of liquids per unit volume, as compared with gases, the amount of heat carried by convection is usually much greater than with gases. The effect of the viscosity of the liquids is usually of much more importance than in the convection of gases.

The viscosity of liquids, as a rule decreases very rapidly with increase in temperature, so that the temperature coefficient of free convection in oil is always positive and has a very large value, but differs greatly for different oils.

In oil-cooled transformers, the importance of this effect was clearly pointed by S. E. Johannesen (The Effect of Different Air Temperatures on Temperature Rise of Electrical Apparatus, The Rose Technic, Rose Polytechnic Insitute, Terre Haute, Ind., Nov., 1904). To quote from this article:

> It is well known that a transformer immersed in thin oil will run cooler than one immersed in thick oil, all other conditions being the same and further, a transformer immersed in paraffin (poured while hot and

allowed to solidify) would burn out if operated at a room temperature of 0 deg. cent., and there would even be danger if it were operated in a room having a normal temperature; but when immersed in a light oil and run in a room having a normal temperature of even say 35 deg. cent., it would operate within safe heat limits. This experiment has been tried.

Specific heat of liquids differs very little at different temperatures, their power to absorb heat being approximately the same at any temperature within the working range of electrical apparatus. Therefore, the efficiency of a liquid acting as a cooling medium (when confined) depends upon its ability to flow, assuming that the points of absorption and dissipation are equally efficient.

The table below is given as an illustration to show approximately the heat which would be dissipated at various room temperatures, and fairly represents results of a heat run of a 100-kw., 60-cycle, 2,000-volt, oil-insulated, self-cooling transformer.

Room temperature	Actual temperature rise	Loss at max. temp. rise watts
5 deg. cent.	60 deg. cent.	1154
25 "	50 "	1191
35 "	45 "	1210

He points out for the class of oil-cooling apparatus that the Institute rule does not apply, as it gives a correction which is in the wrong direction.

COMBINED EFFECTS OF RADIATION, CONVECTION AND CONDUCTION

The heat lost by surfaces is equal to the sum of the heat radiated and the heat carried by convection. It may be of interest to calculate the relative magnitude of these two effects under various conditions. For a surface only slightly above room temperature in air at 20 deg. cent., we may calculate the heat lost by convection by determining the amount of heat that would be conducted through a layer of air 4.3 mm. thickness. For one degree temperature difference the heat carried through such a film would be equal to the heat conductivity of the air, *i. e.*, 0.00025, divided by the thickness of the film in centimeters. This gives 0.00059 watt per sq. cm. per deg. cent. as the convection from a body in the neighborhood of room temperature.

For a body at 100 deg. cent., taking a mean conductivity over this range as 0.000275, we find in a similar way the convection to be 0.00064 watt per sq. cm. per deg. cent.

From equation (**11**) the radiation from a black body only slightly above room temperature (20 deg. cent.) is 0.00057 watt per sq. cm. per deg. cent. From equation (**8**), considering the radiation from a black body at 100 deg. cent. in surroundings of 20 deg. cent., we find the radiation to be 0.00086 watt per sq. cm. per deg. cent.

The total loss of heat from a surface will be simply equal to the sum of the convection and radiation. For most purposes, it is more convenient to deal with surface resistivities, rather than with surface conductivities. The resistivities are obtained by taking the reciprocal of the sum of the radiation and convection. In the following table are given the surface resistivities of plane surfaces, in three different positions, vertical, horizontal, with exposed surface above, and horizontal with exposed surface below. In each case the resistivity at 20 deg. and at 100 deg. is given. Also, the resistivity for the case of a body which does not radiate any heat, and the resistivity for a body radiating as much as a black body. Any actual body will, of course, have a resistivity which lies between these two extremes.

TABLE III.

SURFACE RESISTIVITIES OF PLANE SURFACES

Position	20 deg. cent.	100 deg. cent
Vertical		
No radiation	1700	1560
Full radiation	860	670
Horizontal, exposed above		
No radiation	1540	1430
Full radiation	820	640
Horizontal, exposed below		
No radiation	3400	3100
Full radiation	1150	850

There are some cases where the radiation of heat does not play any part in the heat loss from surfaces. For example, in the interior of machines the circulation of air, may carry away heat, yet no heat will be lost by radiation. In this case, the surface resistance will be independent of the nature of the surface and will be that given in the table above for a case of no radiation.

The effect of air circulation will always be to cut down the surface resistance, but even with relatively high wind velocities, this effect will never cut it down to less than about one-fifth of its value with no wind.

Another important case, where the effects of radiation and convection need to be separated, is in determining surface losses from a piece of apparatus in a room in which the walls are at a different temperature from the air. It is readily seen that if the average temperature of the walls of a room is 10 deg. above the temperature of the air surrounding the piece of apparatus in the room, the apparatus will receive heat by radiation which it must give up by convection. Since at room temperature radiation and convection are about equally effective in removing the heat from a body which is a good radiator, it is evident that the machine will reach a temperature which is about half way between that of the air and that of the walls; that is, the temperature of the surface of the machine will be about five deg. above that of the air surrounding it. Similarly, if the walls are colder than the air, the machine will have a temperature lower than the air. It will be readily appreciated that this effect is by no means negligible, since the walls of a room are often 10 deg. warmer or colder than the air. For example, the roof may be heated by the sun's rays and the air in the whole upper part of the room may be very warm, whereas the air in the lower part of the room may be very much colder. Placing paper or cheese cloth screens around the machine will almost completely prevent this difference of temperature of the air and machine.

As we have seen, small bodies, such as wires, take up the temperature of the air very much more readily than large bodies, and therefore this effect of radiation from the walls will be negligible in the case of wires.

We have seen, that the combined effect of radiation and convection is equivalent to that of a surface resistance which may vary from about 600 to 1700. This resistance is equivalent to that of a layer from 23 to 65 meters of copper or to a layer of from 1 to 3 cm. of rubber.

In calculations of the flow of heat through apparatus it is usually most convenient to determine the thermal resistance of the solid parts and simply add the surface resistance. If we then multiply the result by the number of watts of heat flow we obtain the total drop in temperature from the outside of the machine to the air surrounding it. Of course in actual machines it will usually be very difficult to calculate the thermal resistance of the solid parts. In any case, however, a knowledge of the relative importance of the various factors will be a long step towards the solution ot the problem.

EFFECT OF ROOM TEMPERATURE ON TEMPERATURE RISE OF MOTORS AND GENERATORS

BY

MAXWELL W. DAY and R. A. BEEKMAN

Presented under the auspices of the

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EFFECT OF ROOM TEMPERATURE ON TEMPERATURE RISE OF MOTORS AND GENERATORS

BY MAXWELL W. DAY AND R. A. BEEKMAN

Abstract of Paper

The paper gives the results of certain special tests on motors and an investigation of certain commercial tests on motors and generators, with the purpose of obtaining data which would indicate the effect of room temperature on temperature rise of motors and generators.

The special tests were made in a room the temperature of which could be controlled. The general tendency of these tests was toward a higher rise at the cold room temperature, but the results were not entirely consistent, and hence no general rule could be found for applying a correction.

Curves and data are given showing the methods used and the results obtained, from which the following conclusions were drawn:

1. The present correction rule is wrong and should be abrogated.
2. The considerable variations obtained show the difficulty of making a rule that will include all types of machines or even all parts of the same machine.
3. A consideration of the total temperature obtained when working under normal conditions in the maximum room temperature, is of more importance than the rise of temperature.
4. Further tests leading to the determination of a correct rule, if possible, are desirable.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26–28, 1913.

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(*Subject to final revision for the Transactions.*)

EFFECT OF ROOM TEMPERATURE ON TEMPERATURE RISE OF MOTORS AND GENERATORS

BY MAXWELL W. DAY AND R. A. BEEKMAN

Results of commercial tests on electric motors for the last few years, have given rise to a feeling of doubt concerning the correctness of the A. I. E. E. rule for correcting temperature rises for variations of room temperature from the standard of 25 deg.

In one particular case some motors were tested in the summer and easily met the specified heating limits, but when the customer installed them in the following winter, and tested them, some of the heating limits were exceeded, while on retesting them in the following summer the machines again easily met the specifications.

Arrangements were made, therefore, during the following winter, to test an enclosed motor in a room, the temperature of which could be controlled, and this motor was run for one hour, and also continuously at the following room temperatures: Slightly below zero, 25 deg., and 30 deg. These results are given in Figs. 1 and 2, and show that the temperature rises in the cold room were, in most cases, more than those in the hot room. These figures show values of the rise on the different parts of the machine, with the ones obtained at the same room temperature joined by straight lines. Thus the slope of the lines are indicative only of the relative rises of the different parts under the same conditions, while the position of the lines on the temperature scale, show the relative rises under the different conditions, which is the object of our investigation.

These results seem to be reasonable, in view of the Stefan and

Boltzmann law that the radiation of heat is proportional to the fourth power of the absolute temperature. This law seems to have been ignored in many cases, but was discussed by Dr. Goldschmidt in his paper "Die Grundgesetze der Erwaermung elektrischer Maschinen", published in ***Elektrotechnische Zeitschrift,*** of Sept. 10 and 17, 1908.

This same subject is treated further by Dr. Ludwig Binder in "Ueber Waermeuebergang auf ruhige oder bewegte Luft", published in 1911, in which he shows that the radiation of heat increases 1.2 per cent for each degree of room temperature above ice zero, and 0.62 per cent for each degree of difference of temperature between motor and room. The radiation per degree difference between the motor and the room is 1.85 times as much with a room temperature of 20 deg. and a motor temperature of 100 deg., as if the room were 0 deg. and the motor one deg.

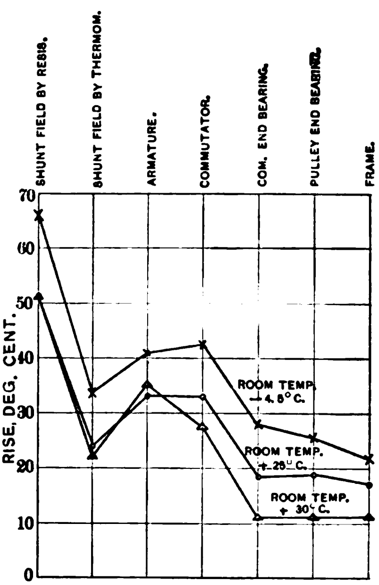

FIG. 1. — TOTALLY ENCLOSED MOTOR, 30 H.P., 550 REV. PER MIN.—52 AMPERES, 500 VOLTS—ONE-HOUR RUN.

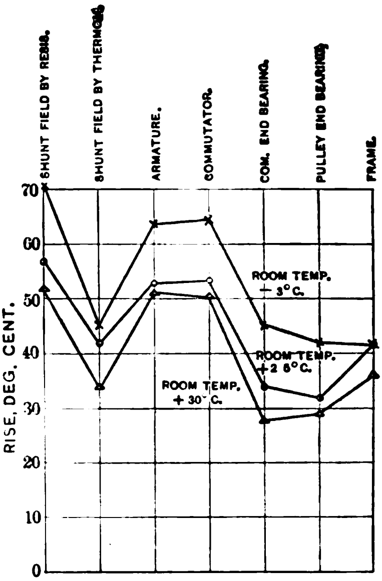

FIG. 2. — TOTALLY ENCLOSED MOTOR, 30 H.P., 550 REV. PER MIN.—30 AMPERES, 400 VOLTS—CONTINUOUS RUN.

However, only a portion of the heat is carried away by radiation as natural convection and forced ventilation must also be considered.

Considering the fact that a few tests already made, indicated the incorrectness of the A. I. E. E. correction rule, which tests were confirmed by the papers mentioned, it was thought desirable to make some careful tests under conditions in which the room temperature could be controlled through a considerable range, and also to consider results already obtained on a large number of commercial tests, which might be comparatively inaccurate individually, but it was thought that with a sufficient number a definite tendency could be discovered.

It was not thought desirable, in the time available, to make a thoroughly scientific investigation to determine a new rule for temperature correction nor to determine the physical causes for these differences, but it was thought that some definite data could be obtained, which would be of interest in determining whether the present correction rule should be followed in the future, leaving for the future the scientific determination of a revised rule.

No attempt has been made in the following, to determine the effect of barometric pressure nor of humidity, although readings were taken during the special tests, but it is understood that moisture in the air in the form of vapor has but little effect on the temperature rises, although moisture in suspension, which is not evaporated before coming in contact with the machine, considerably reduces the temperature rise by absorbing heat from the machine through evaporation.

In the following we will first describe the special tests made in the enclosed room to determine the effect of room temperature, and later will give an analysis of a number of commercial tests made during the last few years.

Description of Special Tests

The special tests were run on two different types of direct-current motors. In each case the machine was a shunt motor with commutating field. The first set of tests was run on a motor rated at 7½ h.p., 825 rev. per min., with a normal current rating of 28.5 amperes. In the second set the motor was rated as 20 h.p., 700 rev. per min., with a normal current rating of 75 amperes.

In each case the normal voltage, 230, was held on the motor armature and commutating field in series, and also across the shunt field. The input into the motor was held constant at two values for each machine, viz.: 28.5 and 14.25 amperes for the first set of tests, while 75 and 37.5 amperes were the values for the second set. The conditions under which these two values were held will be given later.

The tests were run in a room approximately 16 by 14 ft. (4.9 by 4.3 m.) (See, Fig. 3.) Within this room is located an oven generally used for baking coils, the size of which is approximately 11 by 7 ft. (3.4 by 2.1 m.) In this oven are iron pipes, through which steam is ordinarily passed to gain high temperature. These coils were used in these tests for both heating and cooling purposes. In heating, steam was passed through them; in cooling, city water, at a temperature of approximately 13 deg., was used to keep the room temperature as low as possible. Air was kept moving past these coils by the use of three ordinary desk fans.

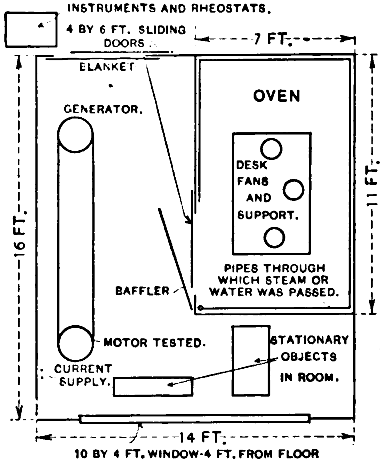
INSTRUMENTS AND RHEOSTATS.
4 BY 6 FT. SLIDING DOORS
7 FT.
BLANKET
GENERATOR.
OVEN
DESK FANS AND SUPPORT.
11 FT.
16 FT.
PIPES THROUGH WHICH STEAM OR WATER WAS PASSED.
BAFFLER
MOTOR TESTED.
STATIONARY OBJECTS IN ROOM.
CURRENT SUPPLY.
14 FT.
10 BY 4 FT. WINDOW-4 FT. FROM FLOOR

FIG. 3.—SKETCH OF TEST ROOM.
Brick walls—corrugated sheet iron ceiling—height of room 8 ft.

This oven has a sliding door about 4 by 6 ft. (1.2 by 1.8 m.) and in the case of the hot room test the temperature of the room proper was maintained very close to 45 deg. by means of regulating the opening of this oven door. Between the motor under test and the oven door a wooden baffler was placed, in order to prevent any direct currents of air from the oven playing upon the motor.

Access to the room is obtained by means of a second sliding door of the same size as that of the oven. This door was kept closed throughout the test, except when it was necessary for the men to pass in and out. In order to prevent this passing in and out from affecting the temperature of the room a blanket was hung in front of the door, and so arranged that the openings were "staggered". The room contains one large window, approximately 10 by 4 ft. (3 by 1.2 m.) reaching from the ceiling to within 4 ft. (1.2 m.) of the floor; this window is of ground glass and was kept closed throughout the tests.

The apparatus used in testing, located in the room, consisted of the motor under test belted to a generator for load, starting box, circuit breakers, and of course, thermometers. The rheostats and instruments were placed outside of the room, so that no heat was developed in the room, except the losses of the motor and generator. There are some stationary objects located in the room, consisting chiefly of wood.

Due to the fact that no convenient place could be obtained for conducting these tests near a suitable direct current generator, from which constant voltage could be obtained, it was necessary to run the test motor from the 250-volt shop circuit. It was found by a preliminary record of a recording voltmeter, that this voltage varied at times, by an amount as great as 20 volts. It was therefore necessary to take steps to maintain constant voltage on the motor. This was done by placing a rheostat in series with the motor and the supply. This rheostat was, as stated above, placed outside of the room and was of the type which is controlled remotely by solenoids. The control for this rheostat was placed directly on the testing table by the voltmeter indicating the motor voltage, and for part of the tests a man was kept constantly varying this in order to hold the rated (230) volts on the motor. For the remainder of the tests, however, a contact making voltmeter was used to control the solenoids on the rheostat, and thus maintain constant voltage.

Besides the original indicating voltmeter record, a recording voltmeter record of the motor voltage was obtained during those tests in which manual control was used. This compelled constant attention on the part of the test men, and hence insured more accurate results.

As stated previously, in the case of the hot room tests the room temperature was maintained very nearly constant at 45 deg. but in the case of the cold room test our object in each case, was to have as cold a room temperature as possible after the temperatures had become constant; *i.e.*, when the heat run was ready to be taken off. Hence, while in the hot room test the room temperature was constant almost from the first, this is not true in the cold room test; but the temperature of the room rose, due to the losses of the motor and generator, until at the end when constant conditions were obtained, it was usually considerably higher than at the beginning of the test.

It was found, by comparing the thermometers that they differed considerably one from the other, and hence all were calibrated with two which read alike, chosen as standard. In order to eliminate the necessity of applying a correction to each thermometer reading, the same thermometers were used to read temperatures on the same parts of the machine throughout the test. In the case of the thermometers on the stationary parts, nearly all were left in the same positions from the start; the only ones removed were those on the pulley end shield and these were removed only when conditions were changed, by removing the fan. In placing the thermometers on the rotating parts at the end of the run the same thermometers were also used, and the men attempted to place these exactly in the same positions.

The instruments used in the test were carefully calibrated before and after the runs, and practically no change was found, so that the relative readings were accurate.

The tests on the 7½ h.p. motor were run under six conditions:

1. Open motor with fan; that is, the motor was provided with a fan on the pulley end and the commutating end completely open to the air.

2. Open motor without fan. In this case the motor was exactly the same, except that the fan on the pulley end was removed.

3. Semi-enclosed motor with fan. Under these conditions, with a fan on the pulley end, a ventilating cover was placed over the commutating end.

4. Semi-enclosed motor without fan. The fan was removed and the same ventilating cover was used as in the preceding.

5. Totally enclosed motor with fan. In this case the ventilating cover was replaced by a totally enclosing cover and the openings in the pulley end shield were closed.

6. Totally enclosed motor without fan. The conditions were the same as the fifth run except with the fan removed.

The tests on the 20-h.p. motor were run only under three of the above conditions, viz.: first, third, and fifth; in other words, in the case of the latter motor we did not remove the fan.

The input into the 7½-h.p. motor was held at 28.5 amperes during the tests run under the first four conditions and at 14.25 amperes during those run under the last two, as the temperatures would have been dangerously high had the normal rated current been held when running as a totally enclosed machine. The input into the 20-h.p. motor was held at 75 amperes during the tests run under the open and semi-enclosed conditions, and at 37.5 amperes during those run under the totally enclosed conditions.

It was the original intention to run four tests under each of the different conditions, two at the cold room and two at the hot room temperature. The check tests at the same conditions were really the same tests with a short interval of time between. That is, the motor was run under one fixed condition until the temperatures were constant; it was then shut down and final readings taken. Then it was immediately started up and the check run put on under the same condition.

This plan was followed, giving 24 tests on the 7½-h.p. motor, and at the end, due to the confusing results on the open motor with fan and the semi-enclosed motor without fan, it was thought necessary to repeat the tests under these conditions. In the case of the open motor with a fan all four tests were repeated, but in the case of the semi-enclosed motor without fan only three check tests were run, because the results of the third at the hot room temperature checked very closely with the two previous ones.

The list of the tests made on the 7½-h.p. motor is as follows:

	Hot room	Cold room
Open motor with fan	4 runs	4 runs
Open motor without fan	2 runs	2 runs
Semi-enclosed motor with fan	2 runs	2 runs
Semi-enclosed motor without fan	3 runs	4 runs
Totally enclosed motor with fan	2 runs	2 runs
Totally enclosed motor without fan	2 runs	2 runs

The list of the tests made on the 20-h.p. motor, is as follows:

	Hot room	Cold room
Open motor with fan	2 runs	2 runs
Semi-enclosed motor with fan	2 runs	2 runs
Totally enclosed motor with fan	2 runs	2 runs

At the beginning of the tests great care was taken in measuring the cold resistance of the shunt fields. The readings were taken after the motors had been in the room a long enough time to allow the temperatures on the motor parts to become the same as that of the room. These cold resistance readings were taken on different days, at different room temperatures. The results, from which the resistance at 25 deg. was calculated, checked within 0.3 of one per cent.

In every case the heat runs were continued until the field readings showed a constant resistance for at least two hours, and the thermometers on the different parts also showed constant temperatures throughout the same period.

Precautions. Following are given precautions which were taken to secure accurate results and obtain as nearly as possible laboratory conditions. Some of these precautions have been given in the description above, but it is thought best to repeat them under this heading.

1. Recording voltmeter record of the motor voltage was kept.
2. Precautions were taken to eliminate drafts and sudden changes of room conditions.
3. Thermometers were kept in the same relative position.
4. The data for any one run were immediately taken from the men running the test, so that their readings during the check run would not be influenced by their knowledge of values previously obtained.
5. The instruments were calibrated before and after the tests to determine if any change had taken place in their errors.
6. The same men performed the same tasks, such as reading the thermometers, and regulating the voltage, in order to eliminate as far as possible, personal errors.
7. All final temperature readings were taken by the same men; that is, no run was taken off by the night force.
8. Four thermometers were read in different positions in the room, relative to the motor, two being directly in the open air and two being immersed in oil.

RESULTS

Special Test. Figs. 4 to 12.

A. 7½-h.p., 825 rev. per min., 230-volt, 28.5-ampere motor.

1. Open motor without fan. Run at rated load until conditions were constant. Two runs at 23 deg. room temperature; one at 44 deg. and one at 45 deg.

Looking at Fig. 4 the results are plotted in the same way as in Figs. 2 and 3. We have averaged the results for the cold room runs and also for the hot room runs, inasmuch as the different tests under these conditions varied only a very little in the value of room temperature, and it was thought that an average of the rises would mean more than curves with check points plotted on them. The same applies to the remaining curves for the special tests.

All parts show lower rise at hot room temperature, except commutator, which became quite rough between runs.

Correction to be applied to the rise per degree difference of room temperature from 25 deg. varies from −0.193 per cent to −0.754 per cent, for the different parts of the machine. The minus sign is used to indicate those corrections which show a lower rise at hot room temperature, and a positive sign the opposite. These signs are assigned on the basis of the slope of the curve of rise against room temperature.

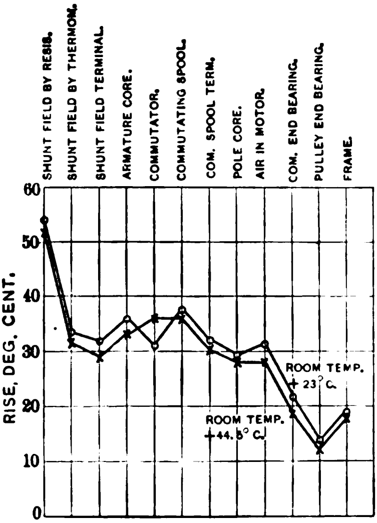

FIG. 4.—OPEN MOTOR WITHOUT FAN—7½ H.P., 825 REV. PER MIN., 230 VOLTS.

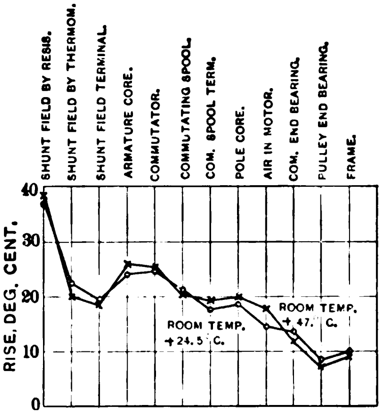

FIG. 5.—OPEN MOTOR WITH FAN —7½ H.P., 825 REV. PER MIN., 230 VOLTS.

2. Open motor with fan. (See Fig. 5.) Run at rated load until conditions were constant. Three runs at practically 24 deg.; one at 26 deg.; two at 44 deg. and one at 47 deg. Results not in the same direction for the different parts.

Shunt field by resistance........	Inconsistent
Shunt field by thermometer......	Rise less at hot room temp.
Armature core and conductor....	Inconsistent.
Commutating spool.............	Inconsistent.

Commutator	Inconsistent.
Pole core	Inconsistent.
Frame	Inconsistent.
Pulley end bearing	Inconsistent.
Commutator end bearing	Rise less at hot room temp.

By "inconsistent" is meant that results point in no definite direction, due, probably, to difference between actual temperature rises being less than experimental error.

Corrections not calculated.

3. Semi-enclosed motor without fan. (See Fig. 6.) Run at rated load until conditions were constant. Three runs at practically 24 deg.; one at 23.5 deg.; two at practically 44 and one at 45 deg. Results not in the same direction for the different parts.

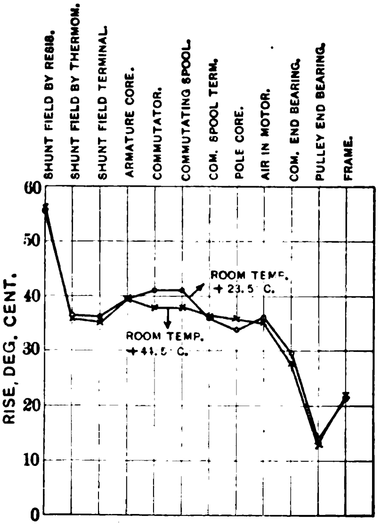

FIG. 6.—SEMI-ENCLOSED MOTOR WITHOUT FAN—7½ H.P., 825 REV. PER MIN., 230 VOLTS.

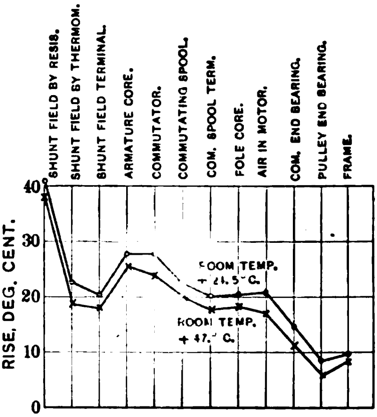

FIG. 7.—SEMI-ENCLOSED MOTOR WITH FAN—7½ H.P., 825 REV. PER MIN., 230 VOLTS.

Shunt field by resistance	Inconsistent.
Shunt field by thermometer	Inconsistent.
Armature core	Inconsistent.
Commutating spool	Rise less at hot room temp.
Commutator	Inconsistent.
Pole core	Rise less at cold room temp.
Frame	Inconsistent.
Pulley end bearing	Inconsistent.
Commutator end bearing	Rise less at hot room temp.

Corrections not calculated.

4. Semi-enclosed motor with fan. (See Fig. 7.) Run at rated load until conditions were constant. Two runs at practically 25 deg.; one at 47; one at 47.5. All parts show lower rise in hot room.

Correction to be applied to rise per degree difference of room temperature from 25 deg. varies from −0.216 per cent to −1.36 per cent.

5. Totally enclosed motor without fan. (See Fig. 8.) Run at one half rated load until conditions were constant. Two runs at practically 20.5 deg. and two at practically 45 deg. All parts show lower rise at hot room temperature.

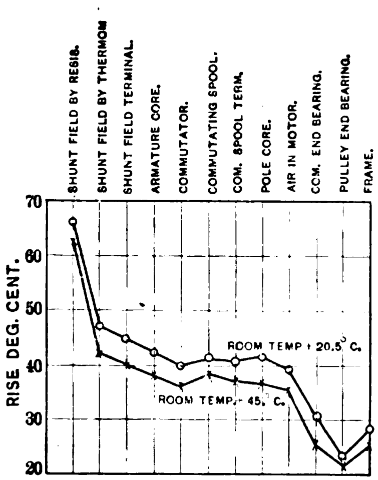

FIG. 8.—MOTOR TOTALLY ENCLOSED WITHOUT FAN—7½ H.P., 825 REV. PER MIN., 230 VOLTS.

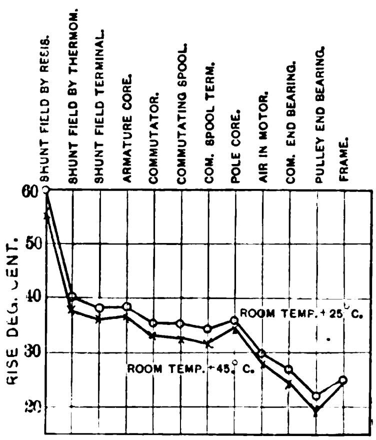

FIG. 9.—MOTOR TOTALLY ENCLOSED WITH FAN—7½ H.P., 825 REV. PER MIN., 230 VOLTS.

Corrections to be applied per degree difference of room temperature from 25 deg. varies from −0.233 per cent to −0.785 per cent.

6. Totally enclosed motor with fan. (See Fig. 9.) Run at one half rated load until conditions were constant. Two runs at 25 deg.; two at 45 deg. All parts show lower rise at hot room temperature.

Correction to be applied to rise per degree difference of room temperature from 25 deg. varies from −0.164 per cent to −0.696 per cent.

It may be well to add that we also tested the open 7½-h.p.

motor with the entire frame covered with asbestos lagging, in order to eliminate radiation losses, as far as possible, and the results were not sufficiently different from the open motor without the asbestos lagging, to warrant our including them in this paper.

B. 20 h.p., 700-rev. per min., 230 volt, 75-ampere motor with fan.

1. Open motor. (See Fig. 10.) Run at rated load until conditions were constant. One run at 25.5 deg.; one at 29; and two at 41.5 deg. All parts except armature core and commutating spool show lower rise at hot room temperature.

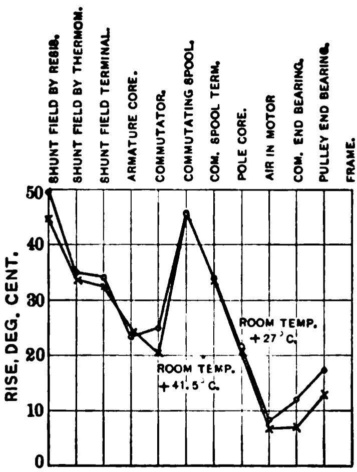

FIG. 10.—OPEN MOTOR WITH FAN—20 H.P., 700 REV. PER MIN., 230 VOLTS.

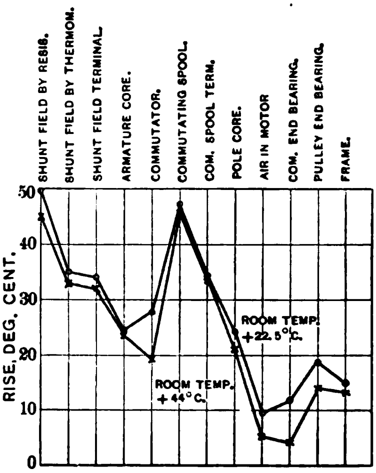

FIG. 11.—SEMI-ENCLOSED MOTOR WITH FAN—20 H.P., 700 REV. PER MIN.

Correction to be applied to rise per degree difference of room temperature from 25 deg. varies from −0.152 per cent to −1.25 per cent, for all parts except those mentioned.

2. Semi-enclosed. (See Fig. 11.) Run at rated load until conditions were constant. One run at 21 deg.; one at 24 and two at 44. All parts, except armature core and commutating spool, show less rise at the hot room temperature.

Correction to be applied to rise per degree difference of room temperature from 25 deg., varies from − 0.314 per cent to −3.19 per cent.

3. Totally enclosed motor. (See Fig. 12.) Run at one half

rated load until conditions were constant. One run at 18 deg.; one at 20 deg.; one at 43 and one at 42.

All parts show lower rise at hot room temperature.

Correction to be applied to rise per degree difference of room temperature from 25 deg. varies from − 0.108 per cent to − 0.916 per cent.

Commercial Tests. In the case of these tests, the data on a great many machines of like rating and condition of heat run, were examined, and as a first step the rises of the different parts were plotted against the room temperatures. Examples of this may be found in Figs. 13 and 15 if we disregard the straight line. The procedure of analyzing the results is as follows:

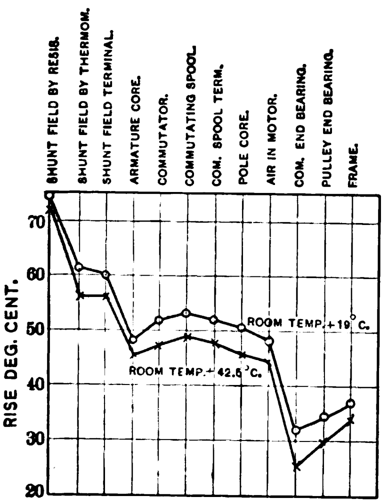

FIG. 12.—TOTALLY ENCLOSED MOTOR WITHOUT FAN—20 H.P., 700 REV. PER MIN.

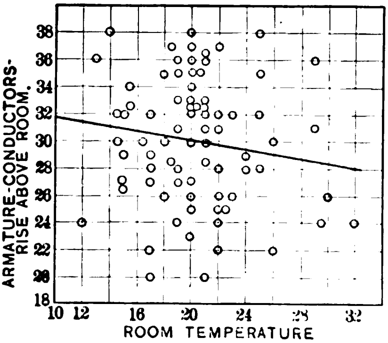

FIG. 13.—ARMATURE CONDUCTORS —98 MACHINES, 3 H.P., 125 VOLTS, 22 AMPERES, 400 REV. PER MIN.

We have given certain observed values of temperature rise in degrees cent. on different parts of electrical machines of the same type, rating and duration of run, at different room temperatures given in degrees cent.

Considering any one part, the second step taken, was to obtain an average of the observed values of rise at each of the different observed values of room temperature. This will then give us a single value of rise for each room temperature, which, when considered with the total number of observations used to get this average, will be equivalent to all the observed values of rise, at any one room temperature, considered individually. An example of this is given in Fig. 14, where any one point represents the average of the number of observations used to determine that point.

We then proceeded by making the following assumptions:

1. That there is a true value of temperature rise based on a standard room temperature of 25 deg.

2. That a change of temperature rise, due to a different room temperature, is proportional to a certain percentage of the difference between that room temperature and 25 deg.

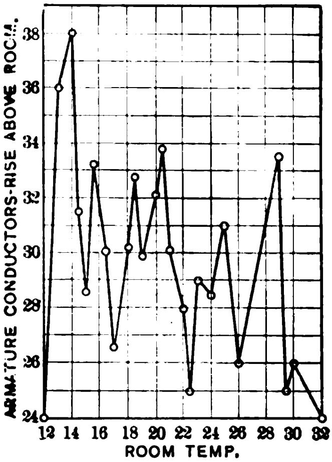

FIG. 14.—ARMATURE CONDUCTORS—98 MACHINES, 3 H.P., 125 VOLTS, 22 AMPERES, 400 REV. PER MIN.

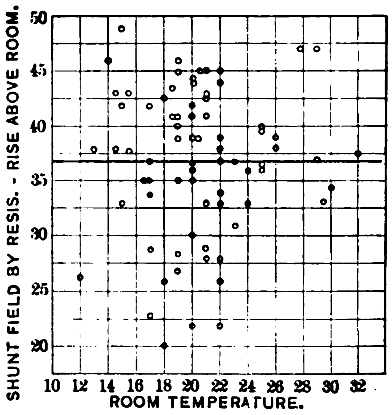

FIG. 15.—SHUNT FIELD BY RESISTANCE—89 MACHINES, 3 H.P., 125 VOLTS, 22 AMPERES, 400 REV. PER MIN.

3. That the actual temperature rise at any room temperature is equal to the true rise at 25 deg. plus a certain percentage of that rise, based on the differences of actual room temperature from 25 deg. plus an error of observation, or accidental variation of test conditions.

4. That each value has a weight corresponding to the number of observations.

5. That the algebraic sum of all the errors is equal to zero.

6. That, from mechanical analogy, each average of observed values, multiplied by the number of observations giving that average, and again multiplied by its distance from the line (*i.e.*

its error) is a force pulling the line toward itself; the lever arm of said force being equal to the observed room temperature minus 25 deg. cent., and that the line, which we are seeking to represent the mean of observed values of temperature rise at different room temperatures, is in equilibrium when all the moments of these forces obtained by multiplying them into said lever arm, are jointly equal to zero.

Then, let

t_1, t_2 etc. = the observed values of room temperature.
B_1, B_2 etc = the average of observed values of temperature rise at t_1, t_2, etc.
N_1, N_2 etc = the number of observations for any one average of observed values.
a, b, c etc. = the error of observation of B_1, B_2 etc.
A = true value or average rise, based on 25 deg. room temperature.
x = the correction per degree difference from 25 deg. to be applied to the rise.

Then,

$$B_1 = A + (t_1 - 25)\, x\, A + a$$
$$B_2 = A + (t_2 - 25)\, x\, A + b$$
$$B_3 = A + (t_3 - 25)\, x\, A + c$$

and so on. Further

$$a = B_1 - A\, \{1 + (t_1 - 25)\, x\}$$
$$b = B_2 - A\, \{1 + (t_2 - 25)\, x\}$$

Or in general, dropping the subscripts

$$\text{An error} = B - A\, \{1 + (t - 25)\, x\}$$

Referring to assumption 5, we must take care, under our system of averages, to multiply or weight each error by the number of observations used to get the average error, and so, in accordance with the said assumption,

$$\Sigma\, N\, [\, B - A\, \{1 + (t - 25)\, x\}\,] = 0$$

In accordance with assumption 6, we then have

$$\Sigma\, N\, [\, B\text{-}A\, \{\, 1 + (t - 25\text{ deg.})\, x\}]\quad (t - 25) = 0$$

We then have two simultaneous equations in A and x, and hence can solve, for these constants and obtain the desired line.

After using the above method we discovered an application of the method of least squares given by Weisbach in *Mechanics of Engineering* pages 95 to 98, applicable to this problem. We have proven to our satisfaction that our method and the method of least squares, as quoted above, are identical.

In accordance with this procedure, we have then added to Figs. 13 and 15 the lines which represent the mean of observed values of temperature rise at different room temperatures.

In the following, the rating and conditions under which the heat run was made, the number of machines tested under similar conditions, and the variation of room temperature will be given. Also the variation of the correction to be applied, based on the rises for the main parts, will be recorded. The parts on the direct current machines, whose rises were reduced to a mean slope, and corrections calculated are;

Shunt field by resistance.
Shunt field by thermometer.
Armature core.
Commutator.

On the alternating current machines,

Armature conductors by thermometer.
Armature conductors by resistance.
Armature core.
Pole core.

In the one case, where induction motors were investigated, only rises on the stator conductors by resistance and by thermometer were reduced to a mean slope.

A. 3 h.p., 125-volt 400/535-rev. per min. direct current totally enclosed motors with a two-hr. heat run at normal load.

1. Run at 535 rev. per min. All parts to which our method was applied show a negative slope, varying from − 0.959 per cent to − 2.75 per cent.

The above values are based on 79 machines, with the room temperature varying from 13 to 26 deg.

2. Run at 400 rev. per min. All slopes negative, varying from − 0.014 per cent to − 0.481 per cent.

The above values are based on 89 machines with the room temperature varying from 12 to 32 deg.

B. 22 h. p. − 650/1050-rev. per min., 120 volt, direct-current, semi-enclosed, motors.

The runs were made until constant. There were 28 machines with the room temperature varying from 23 to 34 deg. The rises of the shunt field and commutator gave a slope of from − 0.601 per cent to − 0.661 per cent, while the armature core gave a slope of + 0.094 per cent.

C. Direct current, open motors; run under normal load until constant.

1. 20-h.p., 1100-rev. per min., 220-volt motors. Here we found 57 machines with the room temperature varying from 15 to 34 deg., which gave corrections for shunt field of − 0.066 per cent by resistance, and − 0.382 per cent by thermometer, while the armature core gave + 0.302 per cent and the commutator + 1.2 per cent.

2. 35-h.p., 600-rev. per min., 220-volt motors. Runs were obtained from 41 machines with room temperature varying from 13 to 32 deg. Here the shunt field by resistance gave a correction of + 1.04 per cent; while the shunt field by thermometer gave − 1.84 per cent; the armature core − 2.03 per cent and the commutator + 0.118 per cent.

3. 60-h.p., 550-rev. per min., 220-volt motors. Twenty-five machines with a variation of room temperature from 12 to 31 deg., gave a correction for the shunt field and armature core of from − 0.241 to − 2.171 per cent; while the commutator gave + 0.993 per cent.

D. Single phase, alternating current generators. Run under normal load until constant.

1. 90 kw., 900-rev. per min., 60-cycle, 2300-volt form "B" generators. Thirty nine machines with room temperature varying from 18 to 29, gave all negative corrections, varying from − 0.055 per cent to − 1.46 per cent.

2. 90 kw., − 900-rev. per min., 60-cycle, 2300-volt form "A" generators. Thirty-nine machines with room temperature varying from 18 to 29 deg., gave corrections varying from − 0.032 per cent to − 2.178 per cent.

3. 120 kw., 900-rev. per min., 60-cycle, 2300-volt generators. Under this rating we found 41 machines with room temperature varying from 16 to 35 deg. All parts, except armature conductor by resistance, gave a negative correction varying from − 0.87 per cent to − 1.224 per cent; while the armature conductors by resistance gave + 0.607 per cent.

4. 120 kw., 1070-rev. per min., 125-cycle-2300 volt generators. Thirty machines with room temperature varying from 15 to 33 deg., gave corrections varying from − 0.7 per cent to − 2.47 per cent.

E. 1 h.p., 1800-rev. per min., 60 cycle, 110-220-volt, induction motors. Run under normal lead until constant.

In the case of induction motors we have but two values of slope; one for the stator conductors by thermometer of − 1.21 per cent, and the other for stator conductors by resistance of

– 0.56 per cent. This is based on 33 machines with a room temperature varying from 13 to 30 deg.

F. 150-h.p.-400/600-rev. per min., 220 volt., direct-current motors.

Tests on these machines are very recent ones; in fact, they have not as yet been completed, and we include them because of the marked difference in the runs at different room temperatures. There are only eight runs on four different machines; run at normal load (400-rev. per min.) for eight hours, and we do not consider these tests in the class of accurate ones. The room temperature varied from 21 to 39 deg. The corrections varied from – 0.278 per cent to – 2.78 per cent.

TABLE I

VALUES OF CORRECTION IN PER CENT

SPECIAL TESTS

Part	7½-h.p. motor				20-h.p. motor—W. F.		
	O. No. F.	S. E. W. F.	T. E. No. F.	T. E. W. F.	T. E.	S. E.	O.
Shunt field by resistance..........	–0.193	–0.318	–0.233	–0.244	–0.108	–0.417	–0.64
Shunt field by thermometer.........	–0.333	–0.678	–0.477	–0.364	–0.375	–0.314	–0.244
Shunt field terminal	–0.412	–0.495	–0.443	–0.164	–0.328		–0.291
Armature core.......	–0.272	–0.310	–0.405	–0.226	–0.248		
Commutating spool	–0.215	–0.392	–0.305	–0.416	–0.345		
Commutating spool terminal.........	–0.249	–0.502	–0.350	–0.366	–0.332		
Commutator.......	*	–0.570	–0.384	–0.366	–0.238	–1.35	–1.25
Pole core..........	–0.103	–0.216	–0.495	–0.209	–0.427	–0.577	–0.341
Commutator end bearing..........	–0.754	–1.36	–0.785	–0.334	–0.916	–3.19	–2.75
Pulley end bearing..	–0.716	–1.32	–0.282	–0.696	–0.536	–1.23	–0.152
Frame............	–0.410	–0.72	–0.514	–0.239	–0.300	–0.761	–0.283
Number of tests.. .	4	4	4	4	4	4	4
Range of room temperature in deg. cent	23 to 45	25 to 47	21 to 45	25 to 45	18 to 43	21 to 44	25 to 42

* Corrections not calculated because data were considered incorrect due to rough commutator. Other blank spaces indicate that on these parts the data pointed in no definite direction and it was not considered advisable to apply the least square method to so few a number of tests.

A general summary of the corrections found, is given in tables I and II. An explanation of the abbreviations used will probably be necessary.

O is used to represent open motor.
S.E. " " " " semi-enclosed motor.
T.E. " " " " totally enclosed motor.
NoF. " " " " motor without fan.
W.F. " " " " motor with fan.

TABLE II
VALUES OF CORRECTION IN PER CENT
COMMERCIAL TESTS

Part	3 h.p. T. E.		22 h.p. S. E.	20 h.p. O.	35 h.p. O.	60 h.p. O.	150 h.p. O.
	400 r.p.m.	535 r.p.m.	650 r.p.m.	1100 r.p.m.	600 r.p.m.	550 r.p.m.	400 r.p.m.
Shunt field by resistance..........	−0.014	−2.75	*	−0.066	+1.04	−2.17	−2.78
Shunt field by thermometer.........	−0.264	−1.03	−0.661	−0.382	−1.84	−1.24	−0.278
Armature core......	−0.187	−0.959	+0.094	+0.302	−2.03	−0.241	−0.212
Commutator.......	−0.481	−1.09	−0.601	+1.20	+0.118	+0.993	
Number of tests....	89	79	28	57	41	25	8
Range of room temperature.........	12 to 32	13 to 26	23 to 34	15 to 34	13 to 32	12 to 31	21 to 39

Part	Alternators				Ind. Motor 1 h.p. O
	90 kw. O-B	90 kw. O-A	120 kw. O-A	120 kw. O-A	
	900 r.p.m.	900 r.p.m.	900 r.p.m.	1070 r.p.m.	1800 r.p.m.
Armature conductors (by res.)........	−0.055	−2.178	+0.607	−0.700	
Armature conductors (by ther.).......	−1.46	−0.032	−1.224	−2.44	
Armature core.......................	−1.35	−0.991	−1.09	−2.46	
Pole core..........................	−1.00	−0.407	−0.870	−2.47	
Stator conductors (by res.)...........					−0.557
Stator conductors (by ther.)..........					−1.21
Number of tests......................	39	39	41	30	33
Range of room temperature..........	18 to 29	18 to 29	16 to 35	15 to 33	13 to 30

* Data not reliable. Other blank spaces indicate that such parts are not found on the particular machines or that such parts were not investigated.

In these tables we have given the different parts with the value of correction found for each part for each type of motor, the number of tests, and the range of room temperature.

We have not included in this table the results on the 7½ h.p.

open motor with fan and semi-enclosed motor without fan, results of which we have said before, showed great inconsistency, and since there were only a few tests, we did not consider it advisable to apply the method used to determine the line of mean slope, that was used in the case of the large number of commercial tests.

Tables I and II represent a total of 2211 values of observed temperature rise on the various types of machines. Of this number 1921 show a negative correction, while 290 show a positive. In other words, about 86.9 per cent indicate that the temperature rise on motors and generators, is less in a hot room than in a cold one while 13.1 per cent indicate the opposite.

The average of all these values of correction is − 0.7 per cent.

In these tests no account has been taken of the temperature of the walls of the room as compared with the temperature of the air. In hot weather the temperature of the walls might be about the same as that of the surrounding air, but in cold weather the walls of a heated room would be of lower temperature than the surrounding air and might affect the direct radiation of the motor to some extent. This matter will be investigated later.

It should be noted that the field rise as determined by resistance falls less with increased room temperature than the reduction of heat dissipated; *i.e.*, if the energy dissipated by the field coil was maintained constant, the field coils would probably show a higher rise of temperature in a hot room. This condition is expected to exist in case of generators.

CONCLUSIONS

We believe that the information submitted warrants us in drawing the following conclusions:

1. The present correction rule is wrong and should be abrogated.

2. The considerable variations obtained show the difficulty of making a rule that will include all types of machines or even all parts of the same machine.

3. A consideration of the total temperature obtained when working under normal conditions in the maximum room temperature, is of more importance than the rise of temperature.

4. Further tests leading to a determination of a correct rule, if possible, are desirable.

NOTES ON INTERNAL HEATING OF STATOR COILS

BY

R. B. WILLIAMSON

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NOTES ON INTERNAL HEATING OF STATOR COILS

BY R. B. WILLIAMSON

Abstract of Paper

This paper deals with the problem of internal heating of stator coils for a-c. generators, particularly those with long cores in which little heat can be conducted from the center of the machine to the ends. In such generators, the heat must pass out to the iron through the insulation, and it is important that the probable temperature difference between inside and outside of the insulation be known at least approximately.

Heat conductivity coefficients for various kinds of insulating materials are given, and a method of calculating the temperature gradient described. Some examples of tests made to determine the difference in temperature between inside and outside of coil are also included.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26–28, 1913.

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NOTES ON INTERNAL HEATING OF STATOR COILS

BY R. B. WILLIAMSON

In the design of alternating-current generators, close inherent regulation was formerly considered desirable, and the output was frequently limited by regulation, rather than by heating. However, with the general introduction of automatic voltage regulators, close regulation has become less important, and for some classes of generators it is now recognized that it may even be very undesirable. This is so in high speed machines of large output, in which low reactance is undesirable on account of the excessive current set up in case of accidental short circuit. The tendency is therefore towards machines having relatively poor inherent regulation, and the limiting output of such is fixed by the allowable temperature rise. It is also becoming common practice to rate generators, particularly those for connection to steam or water turbines, on a maximum basis; usually on the output that can be delivered continuously with a maximum temperature rise of 50 deg. cent. The tendency is to place the heating limit at the maximum point to which the machines can be operated safely for continuous service, thus getting the maximum output possible from a given investment in generating machinery.

Assuming the limit of output to be fixed solely by heating considerations, the question arises as to what maximum temperature is allowable, and to which part of the machine it should refer. Rotor coils on a-c. generators can, if necessary, be insulated safely to withstand maximum internal temperatures as high as 150 deg. cent. by using mica, asbestos or similar material. The excitation voltage is not high and the coils are usually of such shape that this kind of insulating material can be applied in such manner as to make a good mechanical job. With stator coils it is often difficult to use these materials by themselves on account of the relatively high voltage and also because of the irregular shape of the windings. Hence stator coil insulation, in most cases, contains more or less cellulose material, such as cotton tape, treated cloth, etc. Opinions differ as to the maximum temperature at which such material can be operated continuously without deterioration, but a maximum ultimate temperature of 100 deg. cent. in the hottest part may be taken as the limit. It should be noted in passing that metal parts of a generator, not in contact with the coils, as for example the back of the punchings, pole tips, etc., might attain a temperature considerably in excess of 100 deg. cent, without endangering the machine in any way.

Assuming the limit of out put to be such that no part of the stator insulation shall exceed a certain temperature, it is important that the designer should be able to make a reasonably accurate estimate of the maximum temperature. Thermometer measurements on machines under test give the temperature of the outside of the coils and the surrounding parts. Measurements of temperature by resistance give the average temperature of the copper but do not give the maximum temperature unless the coil happens to be heated uniformly throughout its length. In machines having narrow cores, measured parallel to the shaft, considerable heat will flow along the copper to the projecting ends of the coils, which are usually cooler than the part in the slot. On the other hand, in machines such as turbo-generators and high speed waterwheel units of large output, having very long cores, a much smaller proportion of this heat will pass from the part of the coil located in the middle of the machine out towards the ends. Consequently most of the heat liberated from the copper in the slot in the central part of such machines, should be considered as passing through the insulation into the immediately surrounding parts. The highest temperature will thus be on the copper inside the coil and near the central part of the generator. This temperature cannot be measured by taking the increase in resistance of the whole winding, and it is neither safe nor advisable to use temperature coils inside the insulation of the windings on account of the danger of insulation breakdowns and also risk in taking observations. These temperature coils would be directly in contact with the high voltage winding, and therefore a source of danger under regular operating conditions. However, the temperature of the surrounding parts immediately outside the coil is easily obtained by thermometers or temperature coils, and if the temperature difference between copper and iron can be calculated, the safe operating temperature for the outside of a coil in any given case can easily be fixed.

It is therefore very desirable to have some means of predetermining this temperature difference, provided the method can be depended upon to give results close enough for the purpose. It is with the object in view of bringing out discussion and results obtained by others that the following is offered.

The temperature difference between the copper inside a coil and the medium with which the outside is in contact, depends on the rate at which heat is transmitted per unit area of insulating wall, the thickness of the wall, and the heat conducting properties of the insulation. A knowledge of the heat conductivity of various kinds of insulation as used in generators must therefore form the basis of calculation of this temperature difference. Table I shows average values from tests made by Mr. T. S. Allen, and used by the writer, during the past two or three years. Tests on various materials have been recently published by Mr. H. D. Symons and Mr. Miles Walker*, and some of their results are given in Table II.

It will not be necessary for the present purpose to describe in detail the methods used for measuring the thermal conductivity of the different materials, except to state that, in general, a given amount of power was passed through a known area of insulating material and the difference in temperature between the two sides of the wall observed. The specific thermal conductivity was then expressed in watts per square inch per one deg. cent. difference in temperature per one inch, (2.54 cm.)thickness of wall. This conductivity coefficient is here denoted by k_t. It was found in the tests by Messrs. Symons & Walker that cellulose materials, such as cotton, paper etc. had a considerable temperature coefficient. For example, the conductivity at 100 deg. cent. was about 12 per cent higher than at 30 deg. cent. On the other hand, the heat conductivity of mica was found not to change between 20 deg. cent. and 100 deg. cent.

Assuming that, within the range of thickness used for slot insulations, the temperature difference is directly proportional to the thickness of wall, Fig. 1 shows the relation between watts per square inch transmitted through the insulation, and tempera-

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*Harold D. Symons and Miles Walker, *Journal I. E. E.* Vol. 48, May 1912.

ture difference for one-inch thickness. It is to be expected that the values of k_t will vary considerably for different samples of similar material, but Tables I and II show that, even though the tests were made by different observers by somewhat different methods, and on materials that doubtless varied considerably, the results agree quite well. With a sufficient number of tests on a given class of material, there should be no difficulty in obtaining the value of k_t close enough for the purpose in view.

TABLE I

Description	Value of k_t Watts per sq. in. per 1 deg. cent. per 1 in. thickness
1. Horn fibre	0.00186
2. Fish paper	0.00175
3. Empire cloth (not impregnated)	0.00362
4. Empire cloth (impregnated)	0.00432
5. Flexible mica (not impregnated)	0.00207
6. Flexible mica (impregnated)	0.00255
7. 11,000-volt insulation (mica and empire cloth not impregnated)	0.00318
8. Same as 7, impregnated	0.00432

TABLE II

Description	Value of k_t Watts per sq. in. per 1 deg. cent. per 1 in. thickness
(Symons and Walker.)	
1. Varnished cloth tightly wrapped	0.00634
2. Presspahn untreated	0.0042
3. Rope paper untreated	0.00292
4. Rope paper treated with Sterling varnish	0.0042
5. Fullerboard varnished	0.0035
6. Empire cloth and mica-alternate layers tightly wound	0.0053
7. Empire cloth, mica and tape containing air spaces (see test on turbo-generator referred to)	0.0037
8. Built up micanite tube with about 19 per cent shellac	0.0026
9. Built up micanite tube with about 11 per cent shellac	0.0031
10. Solid mica plate	0.00915

Fig. 1 shows very plainly the relatively poor heat conducting properties of air. For still air the value of k_t may be taken as 0.00052. Thus a layer of air one mil thick may retain the heat as much as 10 mils of insulation. The great importance of excluding air from the insulating wall and the desirability of a snug fit between the coils and iron are apparent. In estimating the temperature difference between copper and iron, any air spaces present must be allowed for in determining the heat conductivity of the wall as a whole.

The effect of minute air spaces is also shown by the tests on the various materials. The sample of solid plate mica showed a high conductivity while various kinds of built-up mica had relatively low conductivity. Empire cloth (oiled cambric) is much better than mica as a heat conductor, principally because the small air spaces are well filled with varnish. In every case, impregnating a sample improved its conductivity, the increase in some cases amounting to 25 per cent, on account of elimination of air spaces.

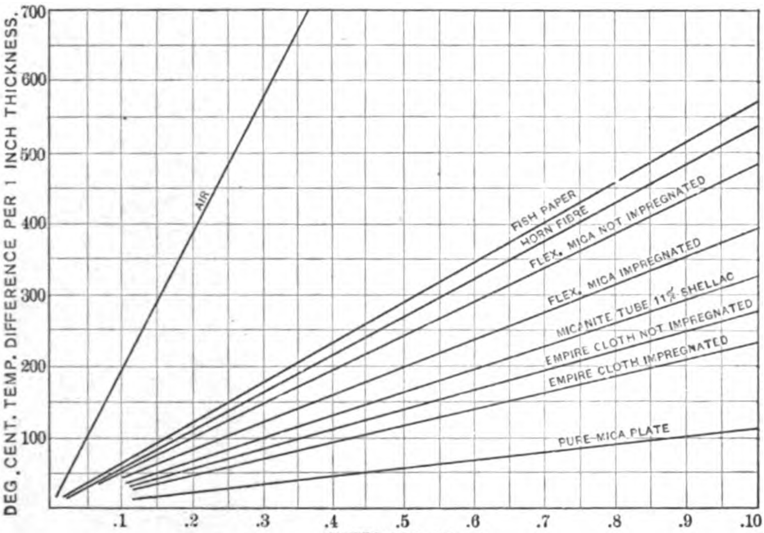

FIG. 1

With a knowledge of the conducting properties of the various materials making up a given insulation, together with the thickness of the layers, including such air clearance as may be present, a value of k_t for the composite wall can be determined. Considering a slot section as in Fig. 2. we will assume that this one inch running length of imbedded coil is located in the center of the machine and that all the heat liberated in the copper has to find its way out through the insulation to the immediately surrounding iron parts. That is, we will assume the worst conditions found in a long machine where little heat can pass from this part to the projecting ends of the coils. In a two-layer arrangement as shown in Fig. 2, the heat liberated in 2 may be different from that in 1 on account of the difference in eddy current loss.* Also the surface through which the heat passes to the iron is greater for 1 than for 2, since 1 has three faces in contact with the iron, while the other has but two. The face of 2 next to the insulating wedge will not be considered since the wedge is usually a very poor heat conductor and has considerable thickness.

Let r = specific resistance of copper = $\frac{0.895}{10^6}$ ohm per $\frac{\text{inch}}{\text{inch}^2}$

at 100 deg. cent., or $\frac{0.83}{10^6}$ at 75 deg. cent.

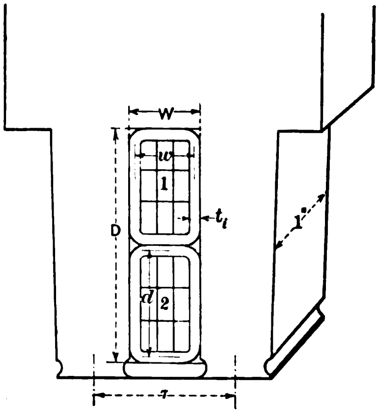

FIG. 2

A = cross section of conductor in sq. in.

I = current in conductor—amperes.

N_c = number of conductors per half slot = number of turns per coil in Fig. 2.

N = number of conductors per slot.

k_e = factor by which eddy $I^2 R$ loss is to be multiplied to allow for eddy currents.

k_i = thermal conductivity of insulating wall including air clearance (watts per sq. in. per deg. cent. per one inch thickness.)

t_i = thickness of insulating wall in inches measured from copper to iron and including clearances.

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*A. B. Field TRANSACTIONS, A. I. E. E. Vol., 24, 1905.

K = ampere conductors per inch of stator circumference.

W = width of slot.

D = effective depth of slot (not including retaining wedge.)

S = current density in conductor, amperes per sq. in.

τ = slot pitch in inches.

w = mean width of coil in inches measured to center of insulation.

d = mean depth of half coil measured to center of insulation.

T_d = difference in temperature deg. cent. between copper and outer surface of coil.

Considering one inch running length of coil, the loss including eddy currents will be

$$\text{Watts per one inch length of coil} = \frac{r\, I^2\, N_c\, k_e}{A} \tag{1}$$

the factor k_e being selected to suit the part of the winding under consideration.

The mean surface through which this heat passes is

$$\text{for } 1 = 2\,d + w \text{ sq. in.}$$

$$\text{for } 2 = 2\,d \text{ sq. in.}$$

hence for 1

$$T_d = \frac{r\, I^2\, N_c\, k_e\, t_i}{A\;(2\,d + w)\; k_t} \tag{2}$$

and for 2

$$T_d = \frac{r\, I^2\, N_c\, k_e\, t_i}{2\, A\, d\, k_t} \tag{3}$$

$\frac{I}{A}$ = current density in stator conductor (amperes per sq.in) = S

Hence (**2**) and (**3**) may be written

$$T_d = \frac{r\, I\, S\, N_c\, k_e\, t_i}{(2\,d + w)\; k_t} \tag{4}$$

$$T_d = \frac{r\, I\, S\, N_c\, k_e\, t_i}{2\, d\, k_t} \tag{5}$$

For most cases it will be sufficiently accurate to treat the slot and coil as a whole and take the area through which the heat passes as $2\,D + W$. The temperature difference then becomes

$$T_d = \frac{r \cdot N\,I\,S\,k_e\,t_i}{(2\,D + W)\,k_t} \;. \qquad (6)$$

In high voltage machines using a small conductor, or in others where the design is such as to limit eddy currents to a small amount, the factor k_e can be omitted.

In (6) $N\,I$ = ampere conductors per slot = ampere conductors per inch x slot pitch, and

$$T_d = \frac{r\,K\,\tau\,S\,k_e\,t_i}{(2\,D + W)\,k_t} \qquad (7)$$

It is interesting in (7) to note the various items on which the temperature difference T_d depends. For a generator of specified voltage and with given insulating materials available, the values of t_i and k_t are practically fixed within rather narrow limits. The designer must therefore proportion the slots and fix the current density S in relation to the specific loading K in such manner that T_d will be within the allowable limits. The permissible value of T_d will depend on the ultimate temperature of the surrounding parts. Thus for a maximum internal temperature of 100 deg. cent. and a maximum rise on the iron of 50 deg. cent. the outside coil temperature would be 75 deg. cent. with surrounding air at 25 deg. cent.; T_d in this case therefore should not exceed 25 deg. cent.

On the other hand, if the design is such that the temperature rise on the iron is only 40 deg. cent under these conditions, T_d could be 35 deg. cent. for the same internal temperature of 100 deg. cent.

In (7) it should be noted that the smaller the slot pitch τ the lower will be the value of T_d, other things remaining constant. That is, the more the winding is subdivided the better the conditions are as regards internal heating. However, there is a limit to which subdivision can be carried without making machines unduly large and expensive, and unfortunately this is specially the case in high-voltage generators where the thickness of insulating wall is relatively large. The internal heating of high-voltage coils thus becomes a difficult matter to handle, especially in large turbo-generators, and it is frequently desirable to wind such machines for lower voltage and use step-up transformers. In high-voltage units, the value of T_d may be surprisingly large if care is not taken to keep the current density and specific loading within such limits that the area of insulation in contact with the iron, can transmit the heat without excessive temperature difference.

As regards the values of T_d obtained by the method here outlined tests, so far as they have been made by the writer, indicate that the calculated difference can be depended on within limits close enough for the purpose. The calculations regarding this temperature difference are also very useful in comparing the merits of different designs.

In one case a 6000-kw. water wheel generator having a core 36 in. (91.2 cm.) long was tested as follows. A temperature coil was placed in contact with the copper before the stator coil was insulated. This temperature coil was placed at the center of the machine and in the part of the stator coil lying in the top of the slot next to the inner periphery of the stator. Another temperature coil was placed outside the insulation so that the difference in the readings allowed the value of T_d to be determined. The machine was run on short circuit at about 25 per cent current overload until temperatures became constant. Under these conditions, the two temperature coils indicated a temperature difference of 19.5 deg. cent. The insulation consisted of a combination of mica and empire cloth. The value of k_t being 0.003. The various constants in this case were as follows:

$$r = \text{(for 75 deg. cent.)} \frac{0.83}{10^6} \text{ ohms}$$

$$I = 470 \quad S = 1675 \quad N_c = 2 \quad k_e = 1.05$$

$$t_i = 0.15 \text{ including clearance} \quad d = 1.62 \text{ in.} \quad k_t = 0.003$$

From (5)

$$T_d = \frac{0.83 \times 470 \times 1675 \times 2 \times 1.05 \times 0.15}{2 \times 1.62 \times 0.005 \times 10^6} = 21.1 \text{ deg. cent.}$$

or 1.6 deg. cent. higher than the observed temperature difference.

In the tests by Messrs. Symons & Walker, already referred to, temperature coils were placed in a 5000-kw. turbo-generator and the observed value of T_d was 20.6 deg. cent. between copper and iron in the slot. The loss per inch (2.54 cm.) length of coil was 2.26 watts making due allowance for eddy currents. The mean area through which the heat passed was 5.3 sq. in. (34.2 sq. cm.) thus giving 0.427 watt per sq. in. (.066 sq. cm.). The thickness of insulating wall was 0.177 in. (4.5 mm.) and k_t thus works out at 0.0037, which checks very well with the values found for similar material when tested in the form of samples.

The writer has other tests on machines at present under way, but these will not be completed in time for the present discussion. As mentioned above, the problem if internal heating is of most importance in long high-voltage machines such as turbo-generators. In case the imbedded part is insulated with mica or similar heat resisting material, or if fabric material in combination with the mica is used simply as a binder and not depended on for insulation, a maximum internal temperature of 150 deg. cent. might be allowable. With a maximum rise of 50 deg. cent. on the iron, and with air at 25 deg. cent. this would allow a value of T_d as high as 75 deg. cent. for this class of insulation. In any event, no matter what kind of insulation is used, or what the allowable value of T_d may be, it is highly desirable that the internal temperature be predetermined as closely as possible and limited to such value that deterioration under long continued heating will be avoided.

METHODS OF DETERMINING BRUSH LOSSES DUE TO CONTACT AND FRICTION

BY

H. R. EDGECOMB and W. A. DICK

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METHODS OF DETERMINING BRUSH LOSSES DUE TO CONTACT AND FRICTION

BY. H. R. EDGECOMB AND W. A. DICK

ABSTRACT OF PAPER

1. Contact voltage losses are caused by resistance of contact between brush and slip ring or commutator. Their values are affected by composition, pressure, temperature, humidity, current density, etc. Test apparatus should control and accurately record all these variables.

Two surface variations, which may cause large errors, have been investigated: (1) The change in the surface of the brush due to continued passage of current causes large momentary fluctuations in the values of contact voltage loss. (2) The thin coating of carbon which adheres to the commutator surface decreases contact voltage loss values by forming a conducting medium between brush and commutator.

The complexity of the problem is shown by the large number of variables, each of which materially affects the contact voltage loss. It is proposed to record the effect of these variables for each brand of brush on standard tabular and diagrammatic forms.

2. The value of the power loss due to brush friction is affected by composition, angle of brush, surface conditions, speed, pressure,etc. Commercial tests are not sufficiently accurate to be of use in getting standard values. Such values can only be obtained when test apparatus is used which controls and records all the variables.

Curves and formulas are proposed which record the effect of the principal variables on each brand of brush.

In conclusion it is urged that tests to determine comparative values for losses due to contact and friction should be made under ideal conditions and that the values thus obtained are more dependable than those of commercial tests now being made, and should supersede them.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26-28, 1913.

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METHODS OF DETERMINING BRUSH LOSSES DUE TO CONTACT AND FRICTION

BY H. R. EDGECOMB AND W. A. DICK

1—DETERMINATION OF CONTACT VOLTAGE LOSSES

I. *Introductory.* Losses in voltage at the brushes of an electric machine are caused primarily by high resistance contact between the brushes and the rotating element (slip ring or commutator). Augmenting this contact resistance voltage loss there is, as stated by F. W. Carter, in *Electrical World*, June 29, 1912, an ionization voltage induced at the point of contact between the brush and the rotating part.

The value of the voltage loss resulting from these two causes is affected by: (a) composition and physical characteristics of brush; (b) composition and surface of rotating part; (c) fit of brush in holder; (d) brush pressure; (e) peripheral speed of rotating part; (f) specific resistance of brush; (g) design conditions which control reversal of current under brush; (h) temperature; (i) humidity; (j) current density; and (k) lubrication. The first seven of these may be made constant for a given test, the last four are more or less variable. It is the fact that the test readings indicate the composite effect of these variables that makes them so difficult to analyze. This has led certain brush manufacturers to state that they are fortunate if they can check results within 25 per cent. Our experience bears out this statement..

II. *Apparatus.* The ideal test apparatus for determining voltage losses due to contact should have facilities for varying pressure, speed, composition of rotating part, temperature, humidity, current density and lubrication, and for accurately measuring degree of variation. Specific resistance, composition of brush and design conditions are of course constant for any given test. The range of variation should be as follows: brush pressure, 0 to 10 lb. per sq. in. (0 to 703 g. per sq. cm.); peripheral speed, 500 to 10,000 ft. (152 to 3048 m.) per. min.; composition of rotating part, copper, brass, bronze, steel and cast iron for collector rings and copper-mica, plain and undercut, for commutators; temperature, up to 100 deg. cent.; humidity up to 100 per cent saturation; current density up to the glowing point of the brushes being tested. Amount of lubrication may be measured by weight. It is assumed that apparatus for these tests must be sufficiently massive to prevent vibration and that the electric circuits should be of ample cross-section. Apparatus should be direct-connected to a source of power in preference to being belted, as the variation in speed and the vibration due to the belt sometimes seriously affect the test.

Most testing outfits are arranged to provide for measuring all these variables and for controlling all except humidity and temperature. Humidity has such an important part in voltage losses that unless it is controlled the record of a test will be seriously affected, and as far as we know, no attempt to do this has been made up to this time. For the control of temperature, however, Dr. Arnold has used an electrically heated collector ring and his researches as recorded in *Elektrotechnische Zeitschrift*, March 21, 1907 have established a very useful set of facts concerning effect of temperature on commutation.

The apparatus used in getting the results later referred to (Figs. 1 and 2,) consists of a d-c. generator, the commutator of which has its bars short-circuited by a number of turns of copper wire soldered around the neck. Six ingoing and six outgoing brushes were used. These were well plated and shunted. Fine copper wire was bound tightly into a groove around the brush near the contact point and insulated leads were brought out along a beveled corner of the brush. A power-operated controller connected the brushes consecutively with a graphic voltmeter making records of about 15 sec. duration for each brush. The return was through a copper leaf brush bearing on the shaft which was grounded to the commutator. The records consisted of a series of dots and indicate quite accurately, the range of travel of the voltmeter needle.

Temperature measurements were made with the potentiometer, using thermocouples inserted in the brushes near the contact surface. Current was measured by an indicating ammeter. Humidity was measured by a hygrodeik.

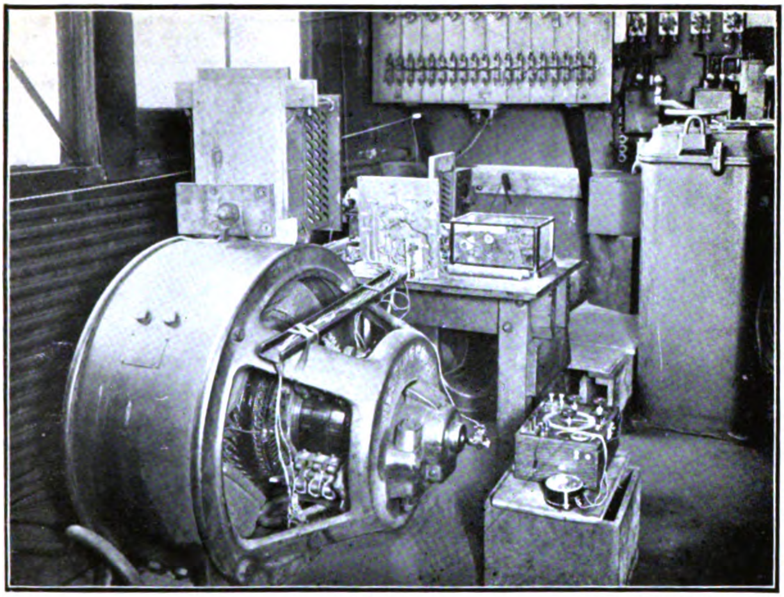

FIG. 1 [EDGECOMB AND DICK]

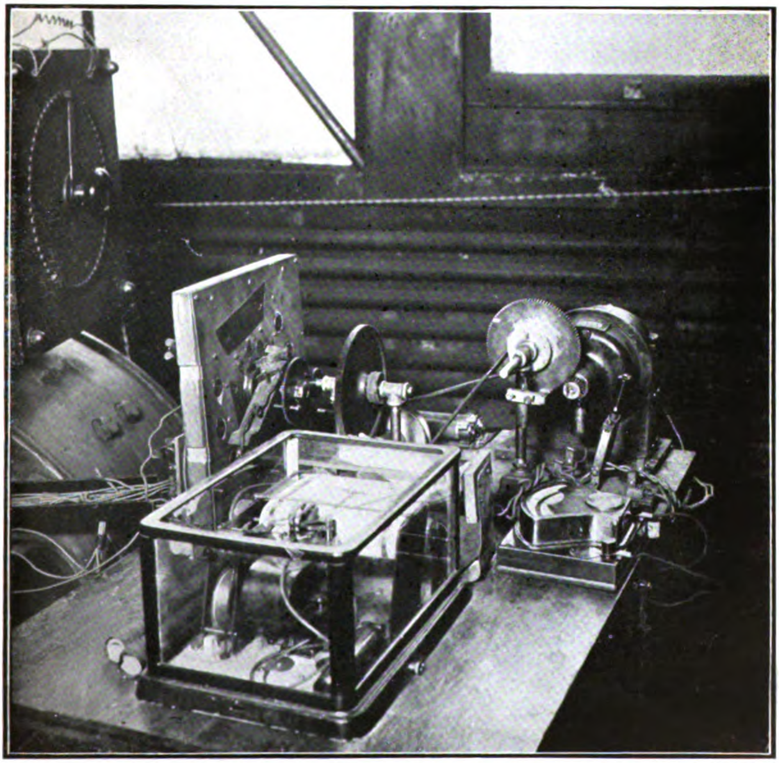

FIG. 2 [EDGECOMB AND DICK

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The graphic meter was frequently calibrated and on its record strip was entered the log of the test, including current density, voltage drop for each brush, temperature, humidity and individual brush pressure.

III—*Surface Variations.* In addition to the variations in brush drop due to causes previously mentioned, the graphic meter has identified two other sources from either of which there might be at least 50 per cent variation on voltage loss.

At the beginning of the test the brushes were fitted as carefully as possible and the machine was run for a day without load to insure a good brush contact. The current was then applied and after a steady temperature was attained it was noted that the voltmeter showed relatively small momentary fluctuation, about 6 per cent (Fig. 3.) The test was continued for 13 hours and during this time the fluctuation increased to 29 per cent. This was checked several times by running the commutator without current for about ten hours and repeating test with practically the same results. During these tests nothing was done to the surface of the commutator.

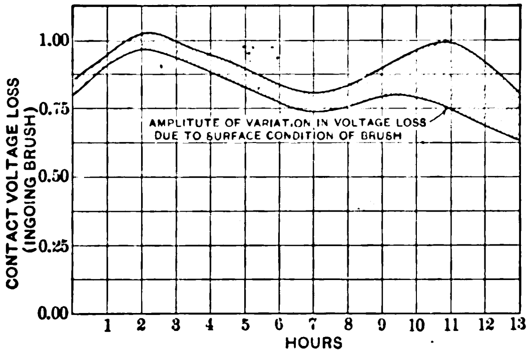

FIG. 3

It is evident that this fluctuation in voltage drop is related to the surface condition of the brush due to the passage of current, as it was controlled by polishing the brush without voltage. We may assume that a disintegrating action takes place, due to the passage of current, which either reduces the actual surface contact or which momentarily separates the brush from the commutator, or which causes migration of the points of contact over paths of greater or less resistance.

The second source of variation has to do with the surface condition of the commutator. After a week's run with current on, when conditions have become as stable as possible the commutator was wiped with clean filter paper and the removal of the surface coating caused an instantaneous increase in the voltage drop, particularly at the ingoing brush. Return to normal conditions occurred in about an hour. Analysis of the material removed showed it to be all carbon, none of the copper oxide having been removed.

As a probable explanation of this phenomenon it is suggested that the fine carbon dust which adheres to the commutator serves as a plastic medium between brush and commutator, adjusting itself to each brush, giving better contact and less voltage loss.

These two causes of variation are brought out because they must be reckoned with in any test for contact voltage loss. It is essential to accurate results that all tests be made under the same conditions and this implies the avoidance of the unstable periods referred to.

Another effect, perhaps of minor importance, was recorded by the graphic meter. At one time the room, was filled with dust and this caused a very marked amplitude in the voltage fluctuations, probably due to the introduction of the particles of dust under the brush and its consequent separation from the commutator.

IV. *Variation Due to Materials and Operating Conditions.*

a. Composition and physical characteristics of the brush: Relative density, proportion of graphitic to plain carbon, the percentage of metal, the percentage of non-conducting abrasive material in the composition, and the temperature, time and manner of firing, all play an important part in determining the contact voltage loss.

b. Composition and surface of rotating part: Voltage loss will be less for material which does not form a non-conducting oxide on its surface. It was noted that brass collector rings containing zinc became coated with an oxide which increased the contact resistance. The oxide was removed with acid and the resistance reduced. Voltage loss is probably increased by the glaze or polish which results from operating a machine.

c. Fit in holder: Continuous contact between brush and rotating part is seriously affected by the inaccuracies of fit of the brush in the brush holder.

d. Brush pressure: It is the practise of brush manufacturers to make contact drop tests at the pressure considered most suitable for the brush being tested, and for this reason very few data on the effect of brush pressure are available. It is known, however, that contact voltage loss varies inversely with brush pressure and as increased pressure causes increased friction, the resulting temperature rise should further decrease the voltage loss.

e. Peripheral speed: Contact voltage loss will increase with peripheral speed because the contact between the brush and rotating part will be made less intimate by the increased jumping of brush due to irregularities on the surface of rotating part.

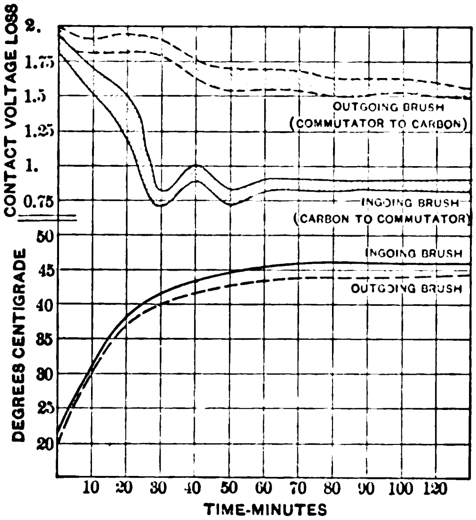

FIG. 4

f. Specific resistance of brush: Contact voltage loss may be expected to vary with the specific resistance of the brush.

g. Design conditions: This feature is not considered, as it is outside the scope of this paper.

h. Temperature: The temperature effect accompanying the passage of current through a brush—commutator circuit is shown in Fig. 4. The maximum efficient temperature appears to be determined either by the glowing point of the carbon or by the amount to which the specific resistance of the brush can be reduced by heating and not cause excessive sparking due to short-circuited coils under the brush. The most efficient point may, however, be higher than it is desirable to use in actual practise.

i. Humidity: Fig. 5 shows a somewhat remarkable relation between contact voltage loss and humidity. In a run of fifty hours the contact drop curve rises and falls with the humidity curve. The fact that the amounts of increase and decrease are not always proportional can be credited to other definite causes such as temperature, surface variation, etc.

j. Current density: Voltage loss will increase with current density.

k. Lubrication: The use of local lubrication is not viewed with favor on account of the resulting gumming of the commutator. Some manufacturers add lubricants to the brushes by impregnation and graphitic brushes are made to depend upon their graphite for lubrication. The effect of a lubricant upon contact voltage loss is clearly a question of the conductivity or non-conductivity of the lubricant used. Graphite should be a less harmful lubricant than paraffin for this reason.

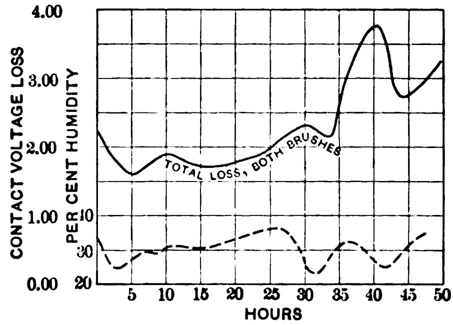

FIG. 5

V. *Conclusions and Recommendations.* When the tests which have been recorded in this paper were begun it was with a conviction that unless the variables which have been the despair of investigators could be eliminated or controlled, very little profit would result from further tests. With means for identifying and controlling these variables, we believe results should check within 5 per cent instead of 25 per cent, and if brush manufacturers have means for accurately determining the characteristics of the brushes now being produced, they will certainly be better able to develop new brushes having better characteristics.

To arrive at a definite figure for the voltage loss due to contact which may be expected from each brand of brush it is essential that tests be made under uniform conditions, particularly as to brush pressure, peripheral speed, surface conditions, composition and diameter of rotating parts, temperature, humidity and current density.

Fig. 6 presents a typical set of curves for recording the data pertaining to each kind of brush. These include the more important characteristics: current density, temperature, pressure and contact voltage loss. Suitable multipliers are to be used to cover composition of rotating part, speed and humidity.

Because of the limited time for making tests the actual voltage loss values for the principal types of brushes cannot be presented in this paper. A complete statement of these figures may be expected at a later date.

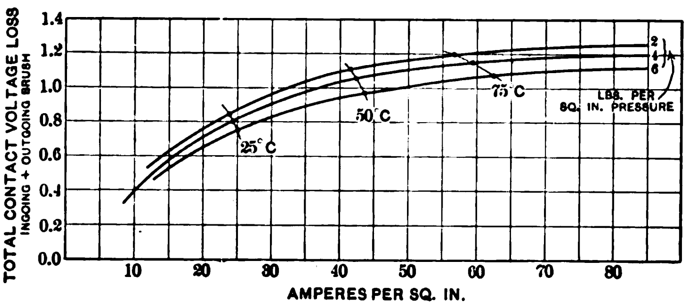

FIG. 6

2—DETERMINATION OF FRICTION LOSSES

Primarily, brush friction is the resistance to motion which occurs when the surface of a revolving commutator or slip ring slides against the surface of a stationary brush.

The problem is a mechanical one and its discussion should consider:

I. The friction formula with reference to modifications for dry surfaces.

II. Test methods and apparatus.

III. Convenient units for expression of brush friction values.

IV. Effect on brush friction of composition of revolving part of brush, and angle of brush, of surface condition of revolving part, of peripheral speed, of brush pressure and of contact area of brushes.

V. Proposed formulas and typical curves for use of designer

I. The friction formula for perfect contact conditions is expressed as follows:

$$K = \frac{F}{N} \text{ or } F = K\,N$$

in which K = coefficient of friction.
F = force required to make one body slide on another.
N = normal pressure.

In the case of dry surfaces, F will be less than $K\,N$ up to a certain value for N, after which F will rapidly increase until seizure occurs. This feature as it affects seizure does not enter into usual brush tests because the pressures are all well below the critical point.

II. Tests for brush friction have been made in two ways: 1st, electrically, by measuring watts expended in overcoming friction of brushes, and 2nd, mechanically, by weighing directly the friction resistance of brushes pressing against a rotating element.

When the electrical method is used the machine under test is connected to a source of power with facilities for measuring the power used. The difference between the power required to maintain rotation with brushes resting on rotating element and the power required when the brushes are removed is the result desired. This method is used in all commercial tests. Too many variables, however, render it unfit for use in investigating the laws of brush friction. We have noted variations of 100 per cent within a few minutes. For this reason the comparison of commercial tests on a large number of machines gives very little reliable information.

In the mechanical method the brushes are supported in a delicately balanced cage, mounted on ball bearings and provided with an arm attached to a spring. This spring resists the tendency to revolution due to friction of brushes and its extension is measured in desired terms on a dial, the direct reading of which eliminates calculation errors. An apparatus of this kind, as used by a leading brush manufacturer, is shown in Fig 7.

If a strict comparison of the coefficients of friction of a number of brush samples is desired, more accurate results will be obtained if the rotating part is a solid ring, preferably copper, with an accurately polished surface. It must be remembered, however, that the behavior of the brush on this nearly ideal surface will be different from its behavior on a commutator having mica segments. It is suggested that this difference be accounted for

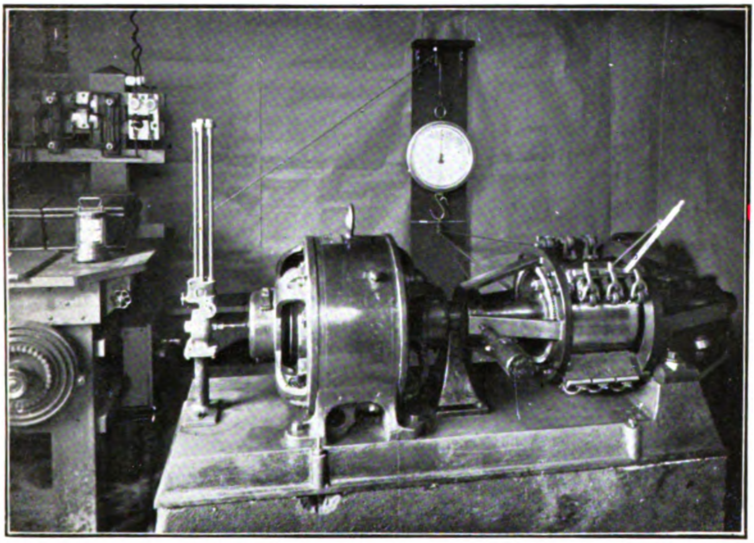

FIG. 7

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by a system of multipliers as follows; (a) a set of constants representing the difference between the surface of the test apparatus ring and the surface of cast iron, steel, bronze, and brass rings and of copper commutators, all assumed to be as well polished as the test ring; (b) a set of constants representing the difference between the surface of a " green " or freshly turned and sandpapered rotating part and the surface of a well polished rotating part; (c) a set of constants representing the difference in friction due to the angle of the brush.

III. The results of brush friction may be expressed in three ways: (a) coefficient of friction, the value of which may be computed from readings obtained electrically or which may be read directly from the dial in the mechanical method. (b) watts consumed due to brush friction, which is obtained, as stated, by the first test method, also by calculations to be mentioned later; (c) percentage of total input, calculated from (b).

IV. The effect of materials and operating conditions may be detailed as follows: When two materials slide on each other their coefficients of friction vary with the nature of either or both of the materials. Each of a large number of carbon brush compositions gives a different coefficient when bearing on the same revolving part. Each of the materials used for slip rings and commutators, such as iron, steel, bronze, and copper, gives a different coefficient on the same brush. In the case of brush composition, friction increases with the hardness and the amount of abrasive, and decreases with increase of graphite and with the addition of other lubricant. Metal-carbon brushes have more friction than plain graphite and about the same as the harder carbon brushes, the friction increasing with the percentage of metal in the brush. Slip ring friction is assumed to be the greatest for cast iron and least for copper, values for the metals generally used decreasing in the following order: cast iron, steel, bronze, brass and copper.

Friction is lowest when brushes are mounted at an obtuse angle with the approaching surface of the rotating part. It is greatest when they are mounted at an acute angle with this approaching surface. Some of this effect is due to the contact of the brush with the walls of brush holder when the box type is used.

Friction is greater when the surface of the rotating part is rough and less when it is well polished. Increasing peripheral speed decreases coefficient of friction and friction generally increases with brush pressure.

V. In the preparation of formulas and curves for the use of the designer we must consider the six variables presented under section IV, as they all effect the value of the friction coefficient. A series of diagrams is proposed, one for each brand of brushes. These diagrams should have separate curves for the various pressures to which the brush is adapted such as the set of curves for one brand shown in Fig. 8; they should show the variation in coefficient due to change in peripheral speed, and they should give the factors used in modifying coefficients to agree with angle of brush, material and surface condition of rotating part.

With a dependable value for the coefficient of friction the power consumption expressed in watts may be calculated, using the formula:

$$\text{watts consumed} = 0.0226\, P\, A\, V\, K$$

in which 0.0226 represents the ratio $\frac{746}{33000}$

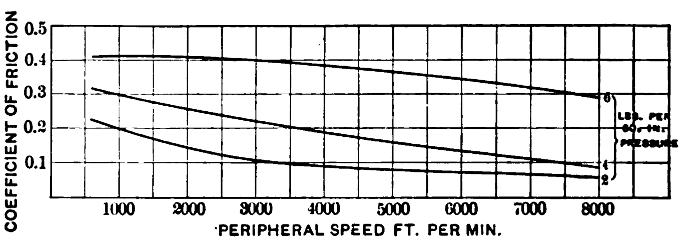

FIG. 8

P = normal brush pressure in lb. per sq. in.,
A = total contact area of brushes in sq. in.
V = peripheral speed of rotating part in ft. per min., and
K = coefficient of friction (adjusted to suit conditions).

In this connection it is interesting to note that a great many formulas are extant, mostly empirical, for determining watts input. Eight of these now in use were applied to a concrete case, with results varying from 910 to 3450 watts. It is likely that the tolerance of these widely varying formulas is explained on the ground that they will all check with actual tests depending on the operating conditions existing at the time of the test.

It is possible that other values might be profitably substituted for "Coefficient of friction," in Fig. 8. For example,

" watts consumed per pound pressure per inch diameter of rotating part " would put the values into convenient form for use on the testing floor.

Because of the limited time for making tests the actual friction coefficients for the principal types of brushes cannot be presented in this paper. A complete statement of these figures may be expected at a later date.

General Conclusions

In discussing brush losses due to contact and friction we have done little more than indicate the avenues along which investigation should proceed and the nature of the results which will be useful to designing engineers. Some troublesome variables have been pointed out, the controlling of which should materially increase the accuracy of results.

Because of the complexity of these tests and the length of time and expense of apparatus necessary to produce dependable results it may be argued that commercial tests, those made on machines actually in course of manufacture and awaiting shipment, should be sufficient to give all necessary information. Our experience in attempting to correlate results of such tests and establish laws therefrom has been exceedingly discouraging, and we are convinced that improvements in the design of electrical apparatus as related to brushes and in the quality of the brushes themselves must result from the establishment of more accurate values for the losses due to brush contact and friction.

There is also every reason to believe that accurate values thus established will be found so much more reliable than actual performance tests that they will be substituted for such tests in the majority of cases.

A LABORATORY INVESTIGATION OF TEMPERATURE RISE AS A FUNCTION OF ATMOSPHERIC CONDITIONS

BY

C. R. BLANCHARD and C. T. ANDERSON

Presented under the auspices of the

Standards Committee

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A LABORATORY INVESTIGATION OF TEMPERATURE RISE AS A FUNCTION OF ATMOSPHERIC CONDITIONS

BY C. R. BLANCHARD AND C. T. ANDERSON

ABSTRACT OF PAPER

This paper is a report on a laboratory investigation of temperature rise as a function of pressure, temperature and humidity of the air.

Physical laws regarding the dissipation of heat in air are important in temperature rise correction as well as in electrical design. Such laws are not yet very well established, and the purpose of the investigation was to determine these. Because of unforeseen difficulties, the results of the tests fell somewhat short of a scientific standard of accuracy. The results, however, are thought to be worthy of attention as approximating very closely the desired laws.

The authors have endeavored, therefore, to present somewhat in detail a description of the apparatus and its manipulation, and to discuss the results, especially as regards their bearing on temperature rise correction.

This paper is considered as preliminary to a more thorough and careful investigation now being made.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26–28, 1913.

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A LABORATORY INVESTIGATION OF TEMPERATURE RISE AS A FUNCTION OF ATMOSPHERIC CONDITIONS

BY C. R. BLANCHARD AND C. T. ANDERSON

The following is a report on laboratory tests made to determine the effect of pressure, temperature and humidity of the air surrounding a heat dissipating body on its rise in temperature above that of the air.

The original purpose of this paper was to investigate the physical laws governing heat dissipation in air and to attempt to apply these laws to the general problem of temperature rise in electrical machinery. But in working up the results of the tests it was found that there was some uncertainty in the derived quantities because of uncertainties regarding the precise effective area of the heat dissipating body, the nature of its surface, the temperature gradient from its interior to its surface, and, furthermore, the heat losses through the leads through which electric power was supplied to the body and by means of which its temperature was measured.

This uncertainty is considered such that careful physical derivations are not warranted, and yet the results are considered sufficiently definite for all practical purposes to determine the effect of the various atmospheric conditions on temperature rise of stationary self-cooled and oil-cooled apparatus. It is, therefore, the purpose to set forth herein the details of the apparatus and its manipulation and the data and curves expressing the desired relations, and to postpone the generalizations until further tests have been made. A rough outline of the proposed derivations will be given, however, as preliminary to a subsequent paper.

An outline of the general method of the tests will first be given. Then the apparatus, manipulation, results and discussion will be taken up in order.

GENERAL METHOD

The method of the tests was as follows:

A resistance coil was suspended in a steel tank containing air. The coil was supplied with electric power. After constant temperature conditions obtained, measurements of coil temperature, air temperature, tank temperature, air pressure and watts input were taken. The difference between the air temperature and the coil temperature was called the temperature rise. The variations of this rise with air temperature, air pressure and input were determined by holding two of these constant and varying the remaining one. These tests were made with dry air except when the effect of humidity was being investigated. The details of the apparatus used and the method of test are taken up in the following sections.

THE APPARATUS

The Test Coil. The heat dissipating body was a coil of 100 ft. (30.48 m.) of insulated copper wire of 0.018 in. (0.457 mm.) diameter with a coat of black enamel of 0.001 in. (0.025 mm.) thickness and one layer of cotton of 0.0025 in. (0.0635 mm.) thickness. Wound turn by turn with this wire was an equal length ot copper wire of 0.005 in. (0.127 mm.) diameter with a coat of enamel 0.00025 in. (0.00635 mm.) in thickness. These two wires formed a coil of 5.08 cm. internal diameter, 7.02 cm. external diameter and 0.635 cm. thickness. The leads which were soldered to the ends of these windings were of copper wire of 0.041 in. (1.04 mm.) diam. with 0.0015 in. (0.038 mm.) enamel. The pyrometer leads were 12.7 and 14 cm. in length; those of the other winding were 12.7 and 16.5 cm. in length. The leads were soldered to pieces of double lamp cord of 16 strands of 0.0125 in. (0.3175 mm.) diameter each with a coating of rubber 0.025 in. (0.635 mm.) in thickness and cloth 0.01 in. (0.25 mm.) in thickness, and 120 cm. in length. The soldered joints at the coil were taped and tied to the coil. The whole coil was wrapped transversely with 140 cm. of hemp string of about one mm. thickness to insure mechanical strength. The coil was then soaked in japan and baked. The soldered joints at the lamp cord were left untaped. These details are given for the benefit of any one who cares to investigate the results of these tests.

The Air Tank. The air tank is shown diagramatically in Fig. 1. It is of cylindrical form, 68 cm. in diameter and 68 cm. in depth. It has a flange at the upper edge to which the cover can be bolted. Pipe connections are made through one side for pressure control. The cover contains two fiber plugs through which the electrical terminals pass. The whole vessel is painted black inside. This tank is supported inside a second tank of 100 cm. diameter and 100 cm. depth, containing oil. Beneath the air tank is an electrical heating element of about two kw. capacity for controlling the temperature.

The Pyrometers. The test coil pyrometer has already been described. The air pyrometer consists of three coils of 0.003-in. (0.076 mm.) cotton-covered wire wound on fiber frames so that practically the whole surface of the wire is exposed to the air. These coils are shielded by square tubes of tin of several times the diameter of the coil. They are open at both ends, allowing free passage of air over the coils, at the same time shielding them from any direct radiation from the test coil. These coils are connected in series. The total resistance of this pyrometer is about 110 ohms. The tank pyrometer consists of three brass spools wound with 0.003-in. (0.076 mm.) cotton-covered wire. These spools are screwed to the tank at various points. The coils are connected in series. The total resistance of this pyrometer is about 100 ohms.

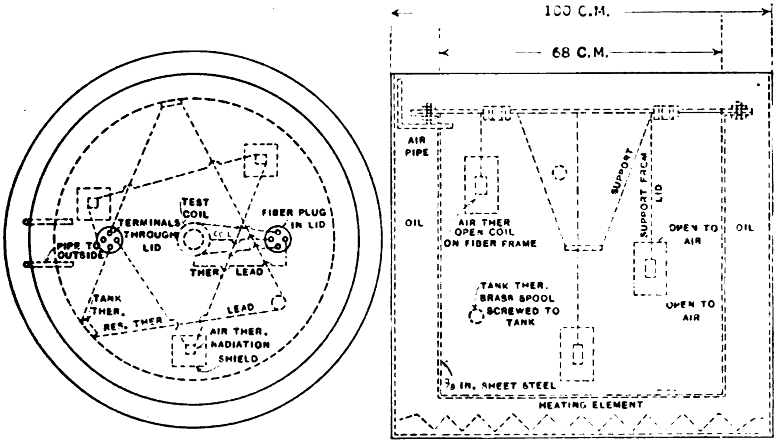

FIG. 1

Each pyrometer is connected through leads in the fiber plugs to the outside of the tank.

The Set-Up. The air-tank then consisted of a test coil suspended in the center of the air tank by twin strings, and loaded by a storage battery through terminals in the cover. The power was varied by a rheostat and read by a direct potential voltmeter and ammeter.

The temperatures were read by measuring the resistances of the pyrometers with a portable bridge. The coils were very carefully calibrated and the temperatures were read from curves.

The air pressure in the tank was controlled by connections with compressed air and vacuum lines. It was measured by means of a mercury column.

MANIPULATION

In Tables I and II are the results of the constant input tests. Each of these tests was made at a constant air temperature in order to determine the effect of pressure alone. Curves in Fig. 2 express the variation of temperature rise with pressure at various air temperatures.

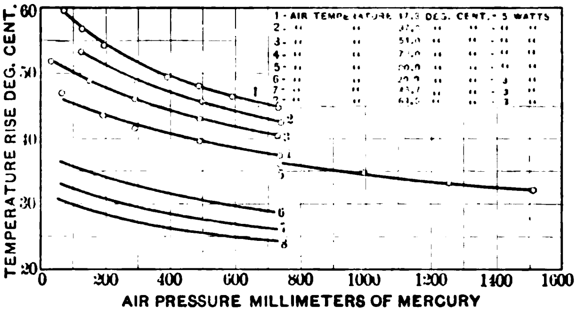

FIG. 2.—TEMPERATURE RISE VS. PRESSURE.

In Table II are the results of the input tests. Each of these tests was made holding air pressure and air temperature constant and varying the watts input. The curves in Figs. 4, 5 and 6 express the variation of temperature rise with watts input at various air pressures and temperatures.

The tests so far outlined were made with dry air. The air before entering the tank was caused to pass through sulphuric acid, calcium chlorid and phosphorus pentoxid.

The last two items in Table I are the results of the humidity tests. In these tests the air was passed through an electric oven which contained a large wetted surface. Great care was taken to pass the air from the humidifier to the test tank without condensation.

RESULTS

The data curves of Fig. 2 express the variation of temperature rise with pressure. The second set of curves on this figure was derived from the input curves of Figs. 4, 5 and 6 by drawing ordinates at three watts and plotting the intersections with the input curves. It will be seen from the curves on Fig. 2 that at normal air pressures there is a variation of temperature rise with pressure of about 1 deg. per 100 mm. Assuming that from

TABLE I.

VARIATION OF TEMPERATURE RISE WITH AIR TEMPERATURE, PRESSURE AND HUMIDITY.

Tank temp.	Air temp.	Coil temp.	Temp. rise	Pressure mm.	Humidity per cent saturation
deg. cent.	deg. cent.	deg. cent.	deg. cent.		
17.5	18	62.8	44.8	732	0
17.8	17.5	64.0	46.5	592	0
17.8	17.5	65.6	48.1	492	0
17.8	17.5	66.8	49.3	392	0
17.5	17.4	68.3	50.9	294	0
17.8	17.5	71.8	54.3	197	0
17.8	17.7	74.5	56.8	127	0
17.8	17.7	77.5	59.8	72	0
39.0	37.8	80.3	42.5	740	0
39.0	37.5	83.2	45.7	500	0
39.2	37.8	86.5	48.7	300	0
39.5	38.0	91.4	53.4	125	0
52.2	50.7	91.2	40.5	732	0
52.5	50.7	93.5	42.8	492	0
52.5	50.5	96.5	46.0	292	0
52.7	51.0	100.0	49.0	152	0
53.0	51.5	103.3	51.8	32	0
76.2	73.5	110.8	37.3	737	0
76.0	73.0	112.5	39.5	497	0
76.0	73.0	114.6	41.6	297	0
76.0	73.0	116.5	43.5	197	0
76.0	73.0	120.1	47.1	67	0
82.5	80.2	116.25	36.0	737	0
82.2	80.0	114.75	34.8	995	0
82.0	79.7	112.9	33.2	1254	0
83.0	80.2	112.3	32.1	1512	0
18.8	19.5	64.4	44.9	732	71
38.5	38.5	81.1	42.6	741	95

TABLE II
VARIATION OF TEMPERATURE RISE WITH WATTS INPUT, TEMPERATURE AND PRESSURE

Tank temp.	Air. temp.	Coil temp.	Temp. rise	Pressure mm.	Watts input
					Total
deg. cent.	deg. cent.	deg. cent.	deg. cent.		
19.3	19.6	30.6	11.0	297	0.892
19.4	19.7	41.5	21.8	297	1.911
19.4	19.9	57.3	37.4	297	3.53
19.4	20.0	73.0	53.0	297	5.27
19.6	20.0	82.5	62.5	97	5.587
19.6	20.1	68.2	48.1	97	4.107
19.6	20.0	49.0	29.0	97	2.29
19.6	20.0	37.8	17.8	97	1.318
66.5	63.8	77.1	13.3	727	1.558
66.5	63.8	78.0	12.2	487	1.560
66.5	63.8	78.8	15.0	287	1.56
66.6	64.0	79.7	15.7	147	1.563
66.5	64.4	80.9	16.5	57	1.564
66.7	64.4	81.3	16.9	17	1.564
67.0	64.5	92.2	27.7	727	3.428
66.7	64.8	116.7	51.9	14	5.121
66.5	64.4	120.9	56.5	54	5.910
66.3	63.9	117.7	53.8	144	5.915
66.6	64.2	114.8	50.6	284	5.961
66.6	64.4	112.0	47.6	484	5.941
66.6	64.4	98.4	34.0	484	4.045
46.7	44.8	59.8	15.0	744	1.626
46.7	45.1	73.8	28.7	744	3.33
47.1	45.3	99.7	54.4	744	6.837
47.3	45.5	74.4	28.8	504	3.094
47.5	45.7	76.3	30.4	304	3.078
47.5	46.6	79.5	32.4	104	3.082
47.7	46.6	108.7	61.6	104	6.205
18.7	19.1	22.8	3.9	737	0.34
18.8	19.1	32.9	14.0	737	1.34
18.8	19.3	46.1	26.9	737	2.80
19.4	19.5	69.5	50.1	737	5.73
19.2	19.4	72.7	53.4	497	5.67
19.3	19.6	58.4	39.9	497	3.95
19.3	19.6	40.3	20.8	497	1.92
19.4	19.7	29.9	10.3	497	0.895
67	64.4	83.2	18.8	724	2.287
67	64.4	84.2	19.8	484	2.272
67	64.5	85.5	21.0	284	2.262
67	64.5	86.8	22.3	144	2.252
67	64.7	88.3	23.6	54	2.246
67	64.7	89.7	25.0	14	2.237

three to five watts input for 80 sq. cm., or from 0.0375 to 0.0625 watts per sq. cm., is a practical range of input, this variation seems to be about what would be expected in stationary apparatus.

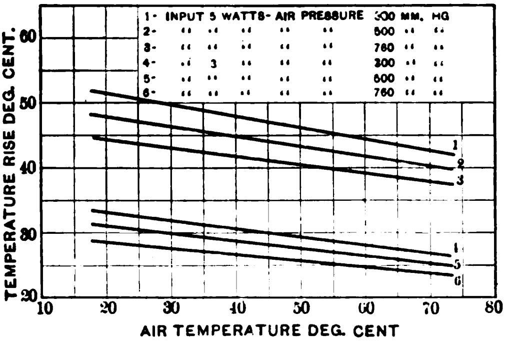

FIG. 3.—TEMPERATURE RISE VS. AIR TEMPERATURE.

According to the Standardization Rules, we have, for a variation of 100 mm. from 760,

$$\frac{860-760}{10} = 10 \text{ per cent correction.}$$

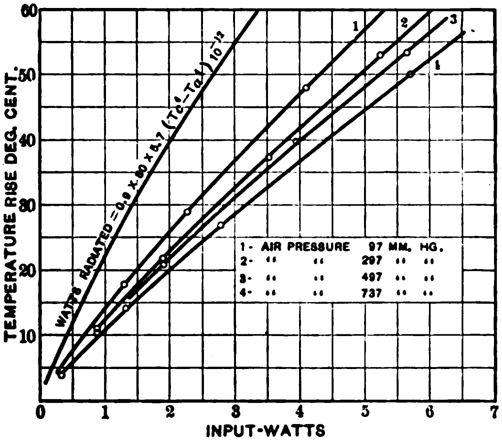

FIG. 4.—TEMPERATURE RISE VS. INPUT.
Air temperature 20 deg. cent.

Assuming a temperature rise of 40 deg. cent. we have 40 + 4 = 44 deg. rise. This correction is four times as large as the results of this test would indicate.

The curves of Fig. 3 are derived from curves of Figs. 2, 4, 5 and 6. They express the variation of temperature rise with air temperature. These curves represent the same range of input as do the pressure curves. The variation according to these curves is about 0.15 deg. per degree centigrade variation of air temperature, in the opposite direction to that assumed in the present Standardization Rules.

The last two items of Table I are the data for the effect of humidity. These points check the dry air points, showing that the effect of humidity is negligible at normal temperatures and pressures.

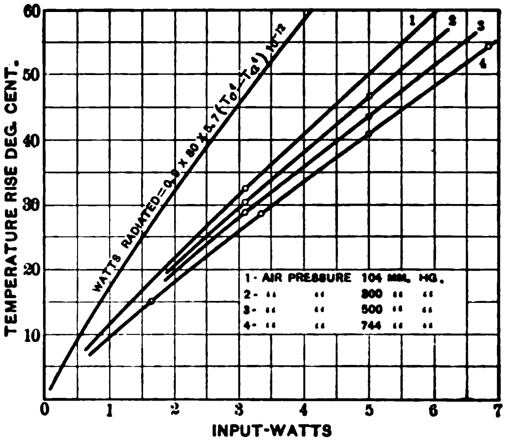

FIG. 5.—TEMPERATURE RISE VS. INPUT.
Air temperature 45.7 deg. cent.

CONCLUSIONS

The temperature rise is a function of the various factors which enter into the dissipation of heat through air. These factors are (1) radiation, that is, a passage of radiant energy, (2) conduction and (3) convection, which is a flow of warm air because of decreased density.

Radiation can be figured according to the law

$$W = K\,5.7\,(T_1^4 - T_2^4)\,10^{-12}$$

where K is unity for a black body and less for any other, depending upon the nature of the heated surface. Assuming 0.9 for K for the test coil and putting

$T_1 = Tc$, the test coil temp. absolute,
$T_2 = Ta$, the air temp. absolute,

and taking the effective radiating area as 80 sq. cm., the watts radiated at various air temperatures and temperature rises * were calculated and plotted in Figs. 4, 5, and 6. These curves express temperature rise as a function of watts input at various surrounding temperatures, if radiation alone be allowed to dissipate the heat. These curves show, by comparison with the data curves, the importance of radiation in the dissipation of heat from a heated body in the open air.

As has already been stated, the results are more or less in error because of losses of heat through the leads, the temperature gradient, and the irregularity in the area.

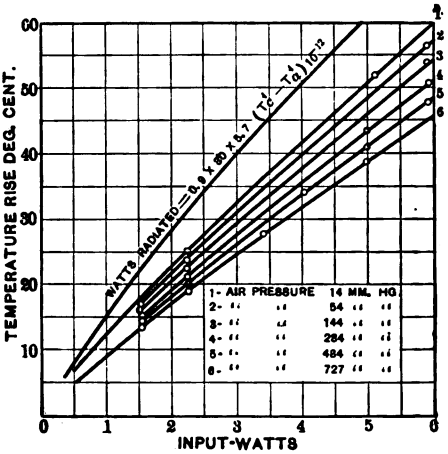

FIG. 6.—TEMPERATURE RISE VS. INPUT.

Air temperature 64.5 deg. cent.

Heat is conducted through the leads a distance depending upon the rate at which it is dissipated from the surface of the leads, which, of course, depends on the temperatures and the nature and area of the surfaces. A correction for this loss, as can be seen, is no simple matter.

The temperature gradient being unknown causes an unknown difference between the coil temperature as measured, and the surface temperature upon which the heat dissipation depends.

Whereas these difficulties forbid derivation of physical laws, they are slight from the engineering standpoint. A set of results which are free from these errors is very desirable, however,

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*See Table III.

TABLE III

Ta deg. cent.	Ta deg. K	$(Ta/1000)^4$	Tc deg. cent.	Tc deg. K	$(Tc/1000)^4$	$r = (Te/1000)^4 - (Ta/1000)^4$	$w = 0.9 \times 5.7 \times r$	$W = 80\,w$	$Te - Ta = Tr$
20	293	0.00738	40	313	0.00961	0.00223	0.01144	0.914	20
20	293	0.00738	60	333	0.01232	0.00494	0.02530	2.026	40
20	293	0.00738	80	353	0.01555	0.00817	0.04200	3.356	60
45.7	318.7	0.01035	65.7	338.7	0.01320	0.00285	0.01460	1.170	20
45.7	318.7	0.01035	85.7	358.7	0.01660	0.00625	0.0321	2.565	40
45.7	318.7	0.01035	105.7	378.7	0.02060	0.01025	0.0526	4.208	60
64.4	337.4	0.013	84.4	357.4	0.01640	0.00340	0.0174	1.40	20
64.4	337.4	0.013	104.4	377.4	0.02030	0.00730	0.0374	3.00	40
64.4	337.4	0.013	124.4	397.4	0.02499	0.01200	0.0615	4.920	60

since the laws of heat conduction and convection in air at various pressures are not as yet well established. Furthermore, the entire problem of heat dissipation in air is important, because when the laws are known electrical machinery can be so designed as to maintain the most efficient system of natural cooling.

Tests which will make possible a physical investigation of heat dissipation in air are being contemplated. A brief outline will be given of the proposed method of attack.

It is hoped to build such apparatus as to dispense with the temperature gradient, surface and heat difficulties. With this apparatus input tests can be made. A set of curves similar to those of Figs. 4, 5 and 6 will determine pressure relations at any temperature and input, temperature relations at any temperature and input, etc. Furthermore, radiation curves similar to those on Figs. 4, 5 and 6 can be plotted, and by subtracting the radiation abscissas from the total values a second set of curves, involving conduction and convection alone, will be the result. Also, by drawing abscissas through such derived curves and noting the intersections, curves of the variation of watts conducted and convected as a function of pressure can be drawn. Similarly, curves can be derived expressing the variation of watts conducted and convected with air temperature. In short, from such a set of data it is possible to derive expressions of the laws of heat dissipation in air.

Such data as those just mentioned should be taken from a surface for which radiation constants are well known. A further investigation of the effect of the nature of the heat dissipating surface is important.

LOSSES IN TRANSFORMERS

BY

W. W. LEWIS

Presented under the auspices of the

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LOSSES IN TRANSFORMERS

BY W. W. LEWIS

Abstract of Paper

It is proposed in the paper to divide transformer losses into *no-load* and *load losses*, the former including *core* and *dielectric losses*, and the latter *resistance and stray losses.*

The magnitude of the stray loss is shown in a large number of commercial transformers and in a few experimental machines.

The relation between the impedance watts and the load losses is discussed, and the conclusion reached that they are practically equal.

Results of tests are given, showing the magnitude of the dielectric losses in high-voltage transformers.

It is recommended that Sections 156 to 159 of the Standardization Rules be amended to define transformer losses as *no-load losses*, including *core* and *dielectric losses*, and *load losses*, including *resistance* and *stray losses*. It is further recommended that all losses be measured at the operating temperature.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26–28, 1913.

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(*Subject to final revision for the Transactions.*)

LOSSES IN TRANSFORMERS

BY W. W. LEWIS

The losses in transformers, as defined in the Standardization Rules of the American Institute of Electrical Engineers, Sections 157-159, are as follows:

157 MOLECULAR MAGNETIC FRICTION AND EDDY CURRENTS measured at open secondary circuit, rated frequency, and at rated voltage —$I\ r$, where I = rated current, r = resistance of primary circuit.

158 RESISTANCE LOSSES, the sum of the $I^2\ r$ losses in the primary and in the secondary windings of a transformer, or in the two sections of the coil in a compensator or auto-transformer, where I = rated current in the coil or section of coil, and r = resistance.

159 LOAD LOSSES, *i.e.*, eddy currents in the iron and especially in the copper conductors, caused by the current at rated load. For practical purposes they may be determined by short-circuiting the secondary of the transformer and impressing upon the primary a voltage sufficient to send rated load current through the transformer. The loss in the transformer under these conditions, measured by wattmeter, gives the load losses + $I^2\ r$ losses in both primary and secondary coils.

Transformer losses more naturally group themselves into two divisions: *no-load losses and load losses.*

The no-load losses are the losses that exist when potential is impressed on the primary of the transformer, with open secondary circuit, and include the loss in the iron and the loss in the insulation; or, *core and dielectric losses.*

The load losses are the losses caused by the load current, and include the loss due to the resistance of the copper and the loss due to the stray or leakage field; or, *resistance* and *stray losses.*

It is the purpose of this paper to give an idea or the magnitude of the stray and dielectric losses, and to recommend certain amendments to the above sections of the Standardization Rules. The term " load loss " will be used in the broad sense (including resistance and stray loss), and the term " stray loss " will be used when referring to the loss defined in Section 159.

TABLE I

STRAY LOSS

Frequency cycles	Rating kv-a.	Rated voltage		Impedance volts in per cent	I^2R watts	Impedance watts	Stray loss watts	Stray loss in per cent of I^2r	Stray loss in per cent of rated kv-a.
		High tension	Low tension						
				CORE TYPE TRANSFORMERS					
25	100	6,600	2,200	1.76	950	1041	91	9.58	0.091
"	"	11,000	460	1.81	1105	1140	35	3.16	0.035
"	"	15,000	375	1.89	1165	1190	25	2.14	0.025
* "	"	33,000	390	15.0	1565	1710	145	9.27	0.145
* "	"	22,000	740	15.7	1440	1496	56	3.89	0.056
* "	"	13,200	370	17	1475	1794	319	21.60	0.319
* 25	145	11,000	370	14.92	1828	2284	456	25	0.314
25	150	12,600	460	2.25	1865	1890	25	1.34	0.017
"	"	6,600	440	2.27	2137	2150	13	0.61	0.009
"	"	20,000	460	2.30	1490	1605	115	7.71	0.077
* 25	165	6,600	430	17	1711	2560	839	49.5	0.508
* "	"	6,600	430	17.5	1915	2445	530	27.7	0.322
* 25	185	23,500	480	15.6	2300	2910	610	26.5	0.330
25	200	22,000	440	2.13	2050	2160	110	5.37	0.055
"	"	11,000	2,200	2.25	1880	1960	80	4.25	0.040
"	"	6,600	2,300	2.44	1980	2100	120	6.06	0.060
25	250	11,000	2,300	1.46	2140	2180	40	1.87	0.016
"	"	13,200	480	2.39	2805	2870	65	2.32	0.026
25	300	11,000	2,300	2.19	2565	2663	98	3.82	0.033
25	350	12,000	2,400	7.81	2730	2950	220	8.06	0.063
"	"	11,000	430	11.7	2575	3560	985	38.2	0.282
25	400	11,000	2,200	2.63	2460	2655	195	7.94	0.049
60	100	12,480	2,300	1.92	1093	1107	14	1.28	0.014
"	"	6,600	460	2.58	1005	1060	55	5.46	0.055
"	"	10,500	2,300	2.59	797	822	25	3.14	0.025
"	"	6,600	2,400	4.23	800	1020	220	27.5	0.220
* "	"	11,000	370	15.1	832	1140	308	37.0	0.308
* "	"	13,200	370	15.3	945	1265	325	33.9	0.325
* "	"	15,000	370	16.9	893	1158	265	29.7	0.265
60	150	6,600	2,300	2.6	1100	1140	40	3.64	0.027
"	"	5,720	2,300	2.83	1214	1318	104	8.57	0.069
"	"	6,600	240	3.8	932	1400	468	50.2	0.312
* 60	165	13,200	430	16.1	1174	1880	706	60.1	0.428
60	200	6,600	2,200	1.9	1020	1160	140	13.72	0.070
"	"	6,600	2,400	1.92	1060	1118	58	5.47	0.029
"	"	9,350	2,080	2.18	1577	1705	128	8.13	0.064

TABLE I—*Continued.*

Frequency cycles	Rating kv-a.	Rated voltage High tension	Rated voltage Low tension	Impedance volts in per cent	I^2R watts	Impedance watts	Stray loss watts	Stray loss in per cent of I^2r	Stray loss in per cent of rated kv-a.
60	250	6,600	550	2.25	1435	1700	265	18.48	0.106
"	"	6,600	480	2.50	1338	1585	247	18.48	0.099
"	"	6,300	200	3.75	2210	2803	593	26.8	0.237
60	300	6,940	2,300	1.72	1836	1925	89	4.85	0.030
"	"	6,600	2,300	2.27	1626	1920	294	18.1	0.098
* "	"	22,000	370	4.18	1790	2400	610	34.1	0.203
"	"	6,000	240	4.19	2150	2810	660	30.5	0.220
60	350	11,000	2,300	1.67	1792	1880	88	4.91	0.025
"	"	6,600	2,300	2.4	1665	2050	385	23.1	0.110
60	350	10,000	440	3.22	1865	2200	335	18.0	0.096
* "	"	34,650	430	18.2	1885	3000	1115	59.2	0.319
60	400	6,800	2,200	2.19	2537	2740	203	8.02	0.051
"	"	22,000	2,500	2.89	2040	2265	225	11.02	0.056
"	"	6,300	200	3.35	2380	3040	660	27.7	0.165
60	500	10,000	3,450	2.03	1905	2330	425	22.3	0.085
"	"	6,600	2,300	2.20	2080	2700	620	29.8	0.124
"	"	10,000	2,300	3.14	3216	3471	255	7.94	0.051

SHELL TYPE TRANSFORMERS

Frequency cycles	Rating kv-a.	Rated voltage High tension	Rated voltage Low tension	Impedance volts in per cent	I^2R watts	Impedance watts	Stray loss watts	Stray loss in per cent of I^2r	Stray loss in per cent of rated kv-a.
40	200	10,000	90	3.76	2350	2740	390	16.6	0.195
25	250	6,600	110	1.64	2310	2400	90	3.9	0.036
25	275	6,940	199	2.96	2905	3280	375	12.9	0.136
60	300	34,600	2,300	3.02	2270	2415	145	6.4	0.048
60	375	6,600	240	4.30	2600	2965	365	14.0	0.098
60	400	44,000	2,300	3.53	2250	2525	275	12.2	0.069
60	500	2,200	608	3.75	3240	4060	820	25.3	0.164
"	"	38,100	7,500	2.90	2960	3115	155	5.25	0.031
"	"	14,450	2,500	3.26	2570	3265	695	27	0.139
"	"	14,450	2,500	3.29	2565	3145	580	22.6	0.116
"	"	13,200	2,550	3.83	2240	2860	620	27.7	0.124
"	"	15,000	2,300	2.15	2800	3060	260	9.3	0.052
"	"	13,200	2,530	1.58	2090	2270	180	8.63	0.036
"	"	6,600	2,300	2.45	2860	3095	235	8.22	0.047
"	"	11,000	2,300	3.01	2525	3260	735	29.1	0.147
"	"	14,000	2,440	3.34	3055	3340	285	9.35	0.057
60	500	23,000	6,600	2.83	3570	4040	470	13.2	0.094
"	"	25,087	2,500	4.68	3420	3890	470	13.7	0.094
60	600	6,930	3,300	2.48	3740	3780	40	1.07	0.007
"	"	33,000	13,860	3.36	2800	3380	580	20.7	0.097

TABLE I—*Continued.*

Frequency cycles	Rating kv-a.	Rated voltage		Impedance volts in per cent	I^2R watts	Impedance watts	Stray loss watts	Stray loss in per cent of I^2R	Stray loss in per cent of rated kv-a.
		High tension	Low tension						
40	750	22,000	600	3.85	4900	5850	950	19.4	0.127
60	750	10,000	3,450	3.18	3965	4760	795	19.9	0.106
*	*	4,000	2,300	3.23	3380	4640	1260	37.4	0.168
*	*	6,600	2,300	4.14	4250	5570	1320	31.1	0.176
*	*	35,475	2,035	4.23	3100	3855	755	24.3	0.101
*	*	60,000	480	4.88	4325	5025	700	16.2	0.093
60	900	23,000	2,300	3.51	5140	6170	1030	20.0	0.113
25	1000	60,000	11,000	4.15	8460	9040	580	6.85	0.058
60	1000	22,000	2,300	2.13	5500	5980	480	8.74	0.048
*	*	21,000	2,500	2.90	5785	6565	780	13.5	0.078
*	*	110,000	22,000	5.00	7070	7300	230	3.25	0.023
*	*	110,000	22,000	5.00	7165	7330	165	2.58	0.017
60	1500	33,000	2,300	4.41	6570	8200	1630	24.8	0.109

* Transformers equipped with internal magnetic shunts.

NOTE.—Each item above represents an average of from one to six transformers.

I. STRAY LOSS

Magnitude of Stray Loss. Table I shows the value of the stray loss, in a number of commercial transformers selected at random. It will be seen that there is apparently no definite relation between impedance voltage and stray loss, or rated voltage and stray loss, although in general the loss increases with increase in impedance voltage, and also for a given size transformer, increases as the low-tension voltage decreases.

Table II gives the results of some impedance tests on an experimental core type transformer, rated 60 cycles, 165 kv-a., 11,000 volts high-tension and 430 volts low-tension. This transformer has four high-tension coils of 308 turns each (two coils per leg) and two low-tension coils of 24 turns each (one coil per leg). The high-tension conductor is 0.215 by 0.055 in. (5.46 by 1.4 mm.) copper, edge-wound; the low-tension conductor consists of ten strips of 0.5 by 0.095 in. (12.7 by 2.4 mm.) copper, arranged five wide and two high.

The first set of readings was taken under normal conditions at 60 cycles. Then some bundles of laminated steel (20 bundles per leg, each containing 18 sheets) were placed horizontally between high-tension and low-tension coils, to form a magnetic shunt, and the remaining three sets of readings were taken at 25, 40 and 60 cycles. The introduction of the shunt has the tendency to exaggerate the losses and therefore to give better readings. The results are plotted in the curves of Fig. 1.

This transformer requires 4 per cent of the normal voltage at 60 cycles to force full load current through the windings, and its impedance losses are 8 per cent in excess of the calculated $I^2 r$ loss. Equipped with magnetic shunt, the transformer requires 19 per cent of the normal voltage at 60 cycles to force full load current through the windings. Its impedance losses are 60 per cent in excess of the calculated $I^2 r$ loss.

TABLE II

IMPEDANCE TESTS—VARIATION WITH CURRENT AND FREQUENCY
TRANSFORMER 60 CYCLES, 165 KV-A., 11,000 VOLTS TO 430 VOLTS

Low-tension (inner) winding short-circuited. (See Fig. 1.)

Frequency cycles	Impedance volts	Per cent normal volts	Amperes	Per cent normal amperes	Impedance watts	I^2R watts	Stray loss in per cent I^2R	Remarks
60	209	1.9	7.51	50.1	317	294	7.83	
"	312	2.84	11.20	74.6	705	662.5	6.42	
"	423	3.85	14.9	99.4	1270	1177	7.8	
"	529	4.81	18.8	125.2	2050	1839	11.48	
"	633	5.75	22.5	150	2915	2648	10.08	
25	254	2.31	3.75	25	82	73.5	11.55	With magnetic shunts
"	526	4.79	7.55	50.4	387	294	31.6	
"	730	6.64	11.25	75	839	662.5	11.54	
"	876	7.97	15.1	100.8	1500	1177	28.3	
"	985	8.95	18.85	125.8	2190	1839	19.1	
"	1076	9.78	22.6	150.8	3040	2648	14.8	
40	427	3.88	3.75	25	109	73.5	48.3	With magnetic shunts
"	835	7.6	7.55	50.4	459	294	56.1	
"	1167	10.6	11.25	75	945	662.5	42.7	
"	1393	12.68	15.1	100.8	1680	1177	42.8	
"	1570	14.28	18.85	125.8	2505	1839	36.3	
"	1713	15.6	22.6	150.8	3405	2648	28.6	
60	580	5.28	3.75	25	—	73.5	—	With magnetic shunts
"	1256	11.4	7.55	50.4	561	294	90.8	
"	1750	15.9	11.25	75	1143	662.5	72.5	
"	2090	19.0	15.1	100.8	1880	1177	59.8	
"	2330	21.2	18.85	125.8	2650	1839	44.1	
"	2570	23.38	22.6	150.8	3725	2648	40.6	

In these test, these high-tension (outer coils) were excited and the low-tension (inner coils) short-circuited. Considerable difference results if the low-tension is excited and the high-tension short-circuited. See Table III. This is due to the different distribution of the flux in the two cases, and the stray loss is reduced to 50 per cent of the $I^2\,r$ loss.

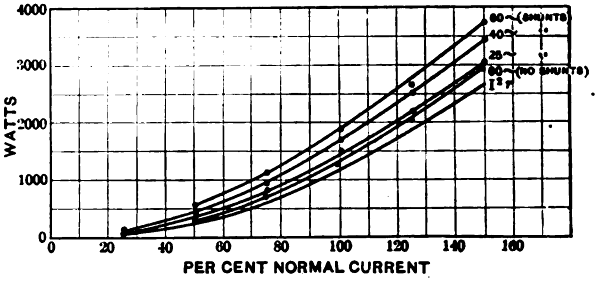

FIG. 1—IMPEDANCE TESTS, 165-KV-A., TRANSFORMER
See Table II.

Tests were made on an experimental transformer rated 60 cycles, 8 kv-a., 800 volts primary and 800 volts secondary. Each winding was composed of two coils, one on each leg, of 160 turns of 0.05 by 0.2i n. (1.27 by 5.08 mm.) copper conductor. The outside coils were excited and the inner coils short-circuited. The tests recorded in Table IV and plotted in Fig. 2 were made, first, with no core; second, with bundles of steel placed vertically between the primary and secondary (two

TABLE III
IMPEDANCE TEST.—TRANSFORMER 60 CYCLES 165 KV-A., 11,000 VOLTS TO 430 VOLTS
High-tension (outer) winding short-circuited

Frequency cycles	Impedance volts	Per cent normal volts	Amperes	Per cent normal amperes	Impedance watts	I^2R watts	Stray loss in per cent of I^2R	Remarks
60	47.8	11.12	192	50	490	294	66.6	With magnetic shunt
"	66.0	15.35	289	75.3	1080	662.5	63	
"	79.5	18.5	386	100.5	1770	1177	50.4	
"	86.0	20.0	443	115.2	2250	1560	44.3	
"	89.5	20.8	474	123.5	2460	1839	33.8	

bundles of 12 sheets each per leg); third, with the laminated steel core in place and no shunts; fourth, with steel core, and magnetic shunts in place between primary and secondary. From these readings, we can separate in a measure the loss in the copper and the core, but only approximately, as the flux distribution is not the same in any two cases.

When a transformer is loaded by the impedance method, the secondary ampere-turns are not equal and opposite to the primary ampere-turns, which is the condition necessary to have no leakage flux. (See third test, Table IV.) This introduces an error in the loss, which, however, is very slight for transformers of ordinary reactance.

TABLE IV

IMPEDANCE TESTS—VARIATION WITH FREQUENCY—TRANSFORMER 60 CYCLES, 8 KV-A., 800 VOLTS PRIMARY, 800 VOLTS SECONDARY

Inside coils short-circuited. (See Fig. 2)

Frequency cycles	Impedance volts	Per cent normal volts	Amperes primary	Amperes secondary	Impedance watts	I^2R watts	Stray loss in per cent of I^2R	Remarks
30	11.25	1.41	10	7.2	79	78.8	0.25	Air core
40	13.10	1.64	10	7.8	83	82.4	0.73	
50	15.10	1.89	10	8.25	87	85.2	2.11	
60	16.90	2.11	10	8.47	90	86.7	3.81	
30	50	6.25	10	3.63	72.2	63.6	13.5	Air core magnetic shunts
40	67	8.37	10	3.96	79	64.6	22.3	
50	84	10.5	10	4.18	85.1	65.3	30.3	
60	98.5	12.3	10	4.27	91.2	65.6	39.0	
30	12.95	1.62	10	9.92	98.5	97.1	1.44	Iron core
40	13.90	1.74	10	9.92	99.5	97.1	2.47	
50	15.90	1.99	10	9.92	100.8	97.1	3.81	
60	17.80	2.22	10	9.92	102.2	97.1	5.25	
30	64	8.0	10	9.85	109.4	96.6	13.25	Iron core magnetic shunts
40	86	10.75	10	9.85	114.3	96.6	18.5	
50	107	13.4	10	9.85	121.3	96.6	25.6	
60	129	16.1	10	9.85	127.5	96.6	32.0	

Relation Between Impedance Watts and Load Losses. To show the relation between the impedance watts and the actual load losses, that is, losses caused by rated current under operating conditions, a series of tests is recorded. The 60-cycle, 165-kv-a., 11,000 volts high-tension and 430 volts low tension transformer, previously described, with the steel magnetic shunt in place between high-tension and low-tension windings, was used. A so-called "bucking" heat run was made, *i.e.*, with the 165-kv-a. transformer and a 365-kv-a. transformer of the same voltage rating, the high-tension windings being connected in series, bucking, and supplied with sufficient voltage to force full load current through the winding of the 165-kv-a. transformer, and the low-tension windings being connected in multiple and excited at normal volts. This is the regular manner of performing heat runs on transformers, and its effect is to supply core loss and impedance watts to the transformer. Another run was made with the experimental transformer loaded on a water box, with normal voltage supplied to the high-tension and normal amperes delivered on the low-tension. The results are given in Table V, together with a set of check readings.

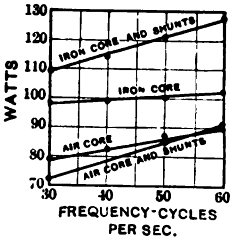

FIG. 2—IMPEDANCE TEST, 8-KV-A., TRANSFORMER
See Table IV.

TABLE V

HEAT RUNS

TRANSFORMER 60 CYCLES, 165 KV-A., 11,000 VOLTS TO 430

Self-cooled

Frequency cycles	Kind of load	Exciting volts	Load amperes	Room temperature	Rise oil	Rise top of tank	Rise bottom of tank	Rise primary	Rise secondary
60	Bucking	430	15	21	39	36	17	37	44
60	Dead	11000	388	21	36	33	17	36	—
Check run:									
60	Bucking	430	15	20	36	32	28	37.5	44.5
60	Dead	11000	384	22	36	33	29	38.5	45

Normal amperes: high-tension 15, low-tension, 384.

All rises in deg. cent. above room temperature.

In the first run the thermometer at bottom of tank was placed nearer to bottom than in second run.

The experimental transformer was then placed in a tank containing cooling coils and operated as a water-cooled transformer on both bucking and dead (water box) load. Three runs were made: first, with 125 per cent normal amperes and 1.3 gal. of water per min.; second, with 125 per cent normal amperes and 0.66 gal. of water per min.; third, with 150 per cent normal amperes and 0.5 gal. water per min. The results are given in Table VI.

We may conclude from the results of Tables V and VI that the bucking method of heat run (supplying core loss and impedance watts) gives substantially the same losses as supplied under normal load conditions (as approximated by the water-box run).

To further check this point, tests are recorded of a small transformer rated 60 cycles, 110 volts primary, 50 amperes secondary. This was built on a two-legged core, with one coil on each leg. The coils consisted of 115 turns of 0.24 by 0.12 in. (6.1 by 3.05 mm.) copper, and 48 turns of 0.048 by 0.13 in. (1.22 by 3.3 mm.) copper, respectively. The 115-turn coil was used as primary and the other coil as secondary. This gives a transformer with very high reactance and accentuates the difference between the impedance watts and the $I^2 R$ watts. Table VII shows the losses as measured by core loss and impedance tests and also as measured by the input-output method. The $I^2 R$ loss + core loss in this case is 97 watts, but the impedance loss + core loss is 398 watts, which figure is closely checked by the input-output test.

TABLE VI
HEAT RUNS
TRANSFORMER 60 CYCLES, 165 KV-A., 11,000 VOLTS TO 430 VOLTS
Water-cooled

Frequency cycles	Kind of load	Exciting volts	Load amperes	Gal. water per min.	Room temperature	Temperature ingoing water	Rise water	Rise oil	Rise tank
60	Bucking	430	18.8	1.3	23	9.3	11.5	21	17
60	Dead	10840	483	1.3	26	10	12.0	22	18.5
60	Bucking	430	18.8	0.66	26	9.9	19	26	21.5
60	Dead	11330	475	0.66	25	8.5	21	28	23.0
60	Bucking	430	22.5	0.50	25.5	9.2	32	37	31
60	Dead	10700	570	0.50	27.0	8 1	32	38	31

All rises in deg. cent. above temperature of ingoing water.

Finally, the tests made on an induction regulator are given. The movable core contained a primary (shunt) winding and a short-circuited winding arranged at right angles to the shunt winding. The secondary (series) winding was on the stationary core. The short-circuited winding consisted of copper bars of large cross-section, thereby naturally giving considerable eddy current losses.

Tests were made with the rotor in two different positions, first the position of maximum boost, which is obtained when the rotor is at one of the limit positions, second at the position of maximum impedance volts, which was found by trial. Table VIII gives the readings of core loss and impedance, loss calculated $I^2 R$ loss, loss by the input-output method and results of heat runs in the two positions. The heat runs were made with the regulator operating as a transformer, the shunt winding being excited and the series winding loaded on a water box.

TABLE VII

COMPARISON OF LOSSES BY INPUT-OUTPUT AND IMPEDANCE METHODS SMALL HIGH-REACTANCE TRANSFORMER, RATED 60 CYCLES, 110 VOLTS PRIMARY, 50 AMPERES SECONDARY

Core loss			Impedance			Total loss
Volts	Amperes	Watts	Volts	Amperes	Watts	
110	21	48	60	21	350	398
Input			Output			
Volts	Amperes	Watts	Volts	Amperes	Watts	
110	21.8	2017	37.25	50	1630	387
Check 110		2020		50	1644	376
					Average	382

$I^2 R$ loss = 49.1 watts
Core loss = 48 "
Total 97.1 "

The difference in heating with the two connections is practically proportional to the difference in total loss.

We may conclude from the tests recorded that the total losses present when the transformer is under load are found by the addition of the no-load losses at normal volts to the impedance loss at normal current, the difference between the impedance losses and the $I^2 R$ loss representing the stray loss.

With transformers of ordinary reactance, the power factor of the impedance reading is sufficiently high (20 to 60 per cent) to leave no question of the accuracy of the wattmeter reading. In the high-reactance transformers, the power factor in some cases is under 10 per cent, and here the wattmeter readings may be somewhat inaccurate.

The loss due to eddy current in the copper is given by a formula of the form

Eddy current loss = (frequency)^2 × (density of leakage flux)^2 × (width of conductor)^2 × a constant.

That is, the eddy current loss is proportional to the square of the frequency, the square of the maximum density of the leakage flux, and the square of the width of conductor at right angles to the leakage field. There is also an eddy current and hysteresis loss in the steel of the core cut by the flux in the impedance test, which is small and is not present as a separate loss when the transformer is under load.

The eddy current loss in the copper can be diminished by reducing the reactance, by reducing the width of copper at right angles to the flux, or by twisting the copper. These losses, however, are bound to exist to a certain extent even in the best

TABLE VIII

LOSSES AND HEAT RUNS

INDUCTION REGULATOR, 55 KV-A., 2200 VOLTS PRIMARY, 125 AMPERES SECONDARY, OPERATED AS A TRANSFORMER

Losses	Maximum boost position	Maximum impedance position
Core loss	877	877
Impedance loss	705	1060
	1582	1937
Primary I^2R at 25 deg. cent.	302	110
Secondary " 25 " "	393	393
Short-circuit winding I^2R	0	160
Core loss	877	877
	1572	1540
Total loss, input-output method	1550	2000
Heat run		
Rise primary above 25 deg. cent.	34	39
" Secondary " " " "	30	36
" Top oil " " " "	30	35
" tank top " " " "	22	29
" tank bottom " " "	14	18

designed transformers, and they are unavoidable in transformers that are purposely designed with high reactance. Their value (plus the other stray losses) may be found, as shown above, by subtracting, from the value of the short-circuit watts, the I^2r watts at the proper temperature.

II. DIELECTRIC LOSSES

In ordinary power transformers the dielectric losses are usually negligible, but in high-voltage testing transformers they may form a large part of the total no-load losses. For a given dielectric at a constant temperature, an equation of this form gives the losses:

$$\text{Dielectric loss} = \text{frequency} \times \text{electrostatic capacity} \times (\text{voltage})^2 \times \text{a constant},$$

TABLE IX

DIELECTRIC LOSSES

TRANSFORMER 3750 KV-A., 120,000 VOLTS HIGH-TENSION, 12,000 VOLTS LOW-TENSION

High-tension in series			High-tension disconnected			
Kilovolts high tension by ratio	Amperes low tension	Watts loss	Kilovolts high tension by ratio	Amperes low tension	Watts loss	Dielectric loss watts
60	2.40	9100	60	2.3	8660	440
90	6.75	18450	90	6.6	17850	600
120	23.4	30400	120	24.0	29050	1350
132	43.0	42200	132	41.3	38100	4100

High-tension winding disconnected in middle. Oil temperature 30 deg. cent. (See Fig. 3.)

the constant depending upon the properties of the dielectric. In addition to the above there is also a small loss due to current leaking through the resistance of the insulation.

Table IX and Fig. 3 show the results of a test made on a shell-type transformer rated 60 cycles, 3750 kv-a., 12,000 volts low-tension, 120,000 volts high-tension. Losses were measured on the low-tension side, first with all the high-tension coils in series, and second, with the high-tension winding open at the middle. The difference between the readings represents the greater part of the dielectric loss. If the windings could be further subdivided, a still further reduction in the loss would result. It will be seen that only above the operating voltage does the loss in the dielectric become appreciable.

Some tests were made on a testing transformer rated 60 cycles 100 kv-a., 500/1000/2000 volts low-tension, 200,000 volts high-tension. This transformer is of the type described by Mr. A. B. Hendricks, Jr., in his paper on *High-Tension Testing of Insulating Materials* (TRANSACTIONS, A. I. E. E., 1911, XXX, I, p. 167). A voltmeter coil of 40 turns is placed at the middle of the high-tension winding, and one end of this coil is connected to the neutral of the high-tension winding and to the ground. The coil is provided with taps at the 10th and 20th turns. The voltage across the whole coil is 400 volts when the transformer is normally excited.

An ammeter and wattmeter placed in the high-tension circuit next to the ground enabled a measurement of the high-tension losses to be taken, at least such of them as are caused by the current measured in the high-tension winding. A 0.2-ampere, 30-volt wattmeter, with the potential coil in series with a multiplier and placed across the 10-turn voltmeter coil, was used. The readings obtained were small, and the total multiplying factor high, so that great accuracy cannot be claimed for the results. This method of measuring takes no account of the loss in the insulation between turns, but only that between high-tension and ground. Table X shows the losses at oil temperatures of 23 deg. cent. and 56 deg. cent., respectively. The difference between the total losses and the loss measured on the high-tension side, decreases with increase in temperature, much more rapidly than we should expect

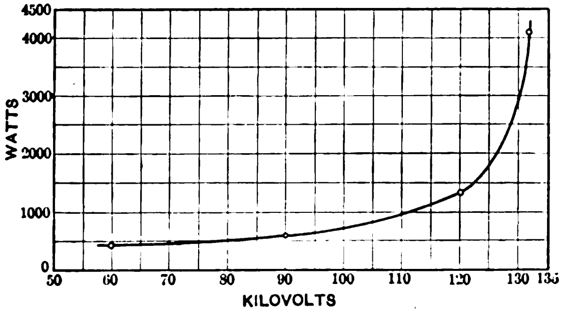

FIG. 3—DIELECTRIC LOSS, 3750-KV-A., 120-KV. TRANSFORMER
See Table IX.

from a decrease in core loss alone (core loss decreasing about 1 per cent for each 10 deg. increase in temperature).

Table XI shows another set of readings taken at various air temperatures from −10 to 22 deg. cent. The results of Table X and the readings at the lowest temperature of Table XI are plotted in Fig. 4.

TABLE X

NO-LOAD LOSS

TRANSFORMER 100 KV-A., 500/1000/2000 VOLTS TO 200,000 VOLTS

Kilovolts high-tension	Amperes low-tension	Total loss watts	High-tension loss watts	Temperature of top oil
100	0.87	682	132	23 deg. cent.
150	1.29	1394	294	
200	1.80	2356	543	
100	1.13	940	440	56 deg. cent.
150	1.68	2086	1174	
200	2.22	3620	2128	

Connected for 2000 volts low-tension, 200,000 volts high-tension. Measurements at 60 cycles. (See Fig. 4)

Table XII gives the results of readings on the low-tension and high-tension at frequencies varying from 47 to 115 cycles per sec. These results are plotted in Fig. 5. The high-tension losses increase somewhat with the frequency, but not directly. On account of the preponderance of the core loss, the total losses decrease with increase in frequency, and consequent decrease in flux density in the iron.

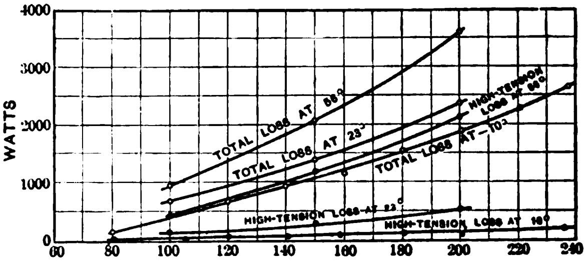

FIG. 4—NO-LOAD LOSSES, 100-KV-A., 200-KV. TRANSFORMER
See Table X.

TABLE XI

NO-LOAD LOSSES—EFFECT OF TEMPERATURE
TRANSFORMER 100 KV-A., 500/1000/2000 VOLTS TO 200,000 VOLTS

Kilovolts high tension by ratio	Amperes low tension	Watts low tension	Kilovolts high tension	Amperes high tension	Watts high tension	Temperature air deg. cent
80		120	80.5	0.0051	10	—10
101		550	105.6	0.0068	20	
120		650	120	0.008	40	
140		900	140.5	0.0093	60	
160		1150	159	0.0106	90	
180.4		1550	181	0.0124	120	
200.6		1900	201	0.0134	140	
221		2300	221	0.0156	———	
238		2650	237	0.0178	220	
129.6		850	129	0.0087	80	—2
142.6		950	142	0.0095	90	
162.2		1300	162	0.0109	120	
185.4		1650	186	0.0131	150	
203		1900	203	0.0145	200	
226		2450	224.6	0.0165	250	
110		550	111.5	0.0077	50	0
154.4		1100	153	0.0105	110	
200		1850	200	0.0143	180	
50		100	50	—	5	3
64		240	65.5	—	15	
76		260	75.5	0.0052	20	
114		600	113	0.008	80	
135		850	134	0.009	100	
177.4		1450	187	0.0123	160	
192.6		1750	193	0.0136	200	
210.8		2200	210	0.0154	240	
233.2		2600	231	0.0168	280	
80	1.14	400	80	0.005	55	13
100	1.37	620	100.5	0.007	100	
120	1.63	820	121.5	0.008	150	
143.6	1.87	1180	143.5	0.010	210	
162.4	2.05	1450	161.0	0.011	280	
181.0	2.29	1800	181.0	0.013	350	
203	2.69	2200	202.2	0.015	440	
219	3.25	2640	217.0	0.016	540	
235	4.20	3050	234.0	0.017	660	
158.8	2.10	1500	158.4	0.0117	360	19
181	2.36	1900	180.0	0.0137	480	
202.8	2.78	2340	201.2	0.0152	600	
80	1.18	470	80	0.0057	80	22
90.2	1.28	570	91	0.0065	97	
100.2	1.42	670	100.6	0.0071	110	
120.4	1.65	925	119.3	0.0084	190	
142.4	——	1250	141.0	0.01	270	
160.0	2.15	1550	159.0	0.0117	370	
180.0	2.40	1900	179.6	0.0135	460	
202.2	2.70	2550	201.2	0.0155	600	

Connected 1000 volts low-tension, 200,000 volts high-tension. All measurements at 60 cycles.
(See Fig. 4)

TABLE XII

NO-LOAD LOSSES—EFFECT OF FREQUENCY

TRANSFORMER 60 CYCLES, 100 KV-A., 500/1000/2000 VOLTS LOW-TENSION, 200,000 VOLTS HIGH-TENSION

Frequency cycles per per sec.	High-tension kilovolts by ratio	Low-tension amperes	Low-tension watts	High-tension kilovolts	High-tension amperes	High-tension watts	Air temperature deg. cent.
47	120	1.72	930	120	0.0065	100	12
	140.4	2.11	1200	139	0.0078	180	
	162.2	3.00	1600	162	0.0088	220	
	182.8	4.69	2050	184	0.0101	300	
	201			201	0.011	350	
	211			210	0.012	400	
57	122.2	1.56	880	121	0.0085	100	12
	141.2	1.78	1150	140	0.0091	150	
	162.4	2.00	1430	161.6	0.0107	240	
	181.8	2.33	1800	182.0	0.0126	300	
	203	3.00	2200	203.2	0.0141	350	
	215	3.71	2500	213.6	0.0151	440	
70	120	1.61	770	119	0.0095	120	12
	142.4	1.91	1100	141.4	0.0118	200	
	158.4	2.12	1340	160	0.0135	250	
	180.6	2.32	1650	180.6	0.0155	300	
	203	2.95	2010	203.6	0.0175	400	
	221	2.68	2400	221.6	0.0188	500	
80	122	1.81	770	121.6	0.0113	150	12
	140.4	2.10	990	140.6	0.135	200	
	160.2	2.41	1290	159.6	0.0159	250	
	179.4	2.64	1550	179.0	0.0175	300	
	201	2.96	1900	201.0	0.0193	440	
	225	3.26	2350	223.2	0.0219	550	
90	122.2		700	121	0.13	140	14
	139.2		850	139	0.015	200	
	162.6		1100	162.4	0.018	300	
	180.6		1400	180.6	0.020	400	
	201.0		1750	202	0.022	560	
	221		2200	221.2	0.025	650	
115	121		700	121.6	0.017	140	14
	142.4		850	142.6	0.0195	250	
	160.4		1100	160.0	0.0221	300	
	180.6		1450	181.0	0.0248	400	
	201.0		1650	201	0.0277	550	
	223.2		2200	223.2	0.312	700	

Connected for 1000 volts low-tension, 200,000 volts **high-tension (See Fig. 5).**

In Table XIII are given the results of an 11½-hour heat run at normal voltage, open circuit. During this time the temperature at the top of the oil rose 35 deg. cent. above its initial temperature, the total losses increased 62 per cent and the high-tension losses increased 263 per cent. Losses are plotted against increase of temperature and increase of high tension loss against increase of temperature, in Fig. 6. It will be seen from this that the loss goes up about as the square of the deg. cent. increase in temperature.

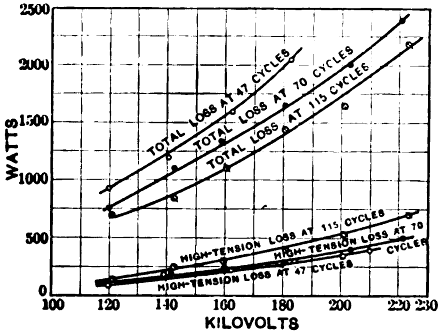

FIG. 5—NO-LOAD LOSSES, 100-KV-A., 200-KV. TRANSFORMER
See Table XII.

TABLE XIII
NO-LOAD LOSSES—VARIATION WITH TEMPERATURE
TRANSFORMER 60 CYCLES, 100 KV-A., 500/1000/2000 VOLTS TO 200,000 VOLTS

Hours heat run	Deg. cent. rise oil	Total watts loss	Low-tension amperes	High-tension loss	High-tension amperes	Increase in high-tension loss
0	0	2234	1.74	587	0.02	0
1	4	2268	1.75	587	0.02	0
2	7.2	2346	1.76	660	0.02	73
3	10.8	2424	1.77	734	0.02	147
4	14	2508	1.81	880	0.02	293
5	17	2610	1.83	1027	0.02	440
6	20.2	2774	1.88	1174	0.02	587
7	23	2920	1.92	1321	0.023	734
8	26	3040	1.97	1468	0.023	881
9	28.5	3184	2.0	1614	0.025	1027
10	31	3326	2.1	1761	0.025	1174
11	34	3560	2.2	2055	0.025	1468
11.5	35	3620	2.22	2128	0.025	1541

Rises above 21 deg. cent., initial oil temperature.

Transformer connected for 2000 volts low-tension, 200,000 volts high-tension. (See Fig. 6.)

A series of tests was conducted on a testing transformer, No. 630263, rated 60 cycles, 500 kv-a. 1100/2200 volts low-tension, 750,000 volts high-tension. To eliminate the effect of variations in temperature, the oil was kept circulating and maintained at a constant temperature of 70 deg. cent. A 500-kw., 60-cycle generator was used, the connections being changed at various points on each curve, in order to operate the machine at nearly normal density and prevent distortion of the wave shape. When the connections were changed and readings repeated, an average of the two readings was plotted.

Phase meter and oscillograph tests showed the current to be leading at all voltages, except the very low ones (under 100 kv.) where the power factor approaches unity.

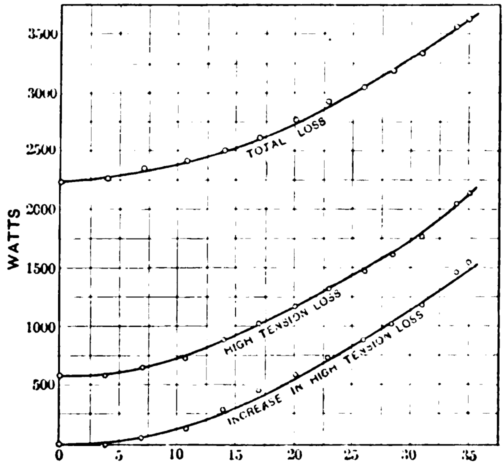

FIG. 6—NO-LOAD LOSSES, 100-KV.-A., 200-KV. TRANSFORMER
See Table XIII.

Losses were measured on the low-tension side only. The following curves were taken:

1. Without leads
    - a. Middle of high-tension winding grounded.
    - b. High-tension not grounded.
    - c. One end of high-tension grounded.
2. With leads.
    - a. Middle of high-tension grounded.
    - b. High-tension not grounded.
    - c. One end of high-tension grounded.

The results are given in Tables XIV to XIX inclusive, and plotted in Fig. 7. As the losses with the winding not grounded are practically the same as the losses with the middle grounded, the latter tests are not plotted. With one terminal grounded the losses are considerably increased, as the end of the winding in this case is at double the potential above ground that it is in the first two cases. When the leads are connected, the losses are increased due to corona on the terminal choke coils and to the boost in high-tension voltage caused by the capacity of the leads. Even without leads, there is considerable boost in voltage, as may be judged from the fact that with center of high-tension winding grounded, a voltage of 650 kv. by ratio caused a discharge across a needle spark gap of 75.5 in. (192 cm.), equivalent approximately to 750,000 volts; and with one terminal grounded, a voltage by ratio of 375,000 caused the discharge of a 50.5-in. (128 cm.) gap equivalent to 500,000 volts.

TABLE XIV

NO-LOAD LOSSES—WITHOUT LEADS AND WITH HIGH-TENSION TERMINALS FREE FROM GROUND

TRANSFORMER 60 CYCLES, 500 KV A., 1100/2200 VOLTS TO 750,000 VOLTS NO. 630,263

Kilovolts high-tension by ratio	Volts low-tension	Amperes low-tension	Watts	Generator connection
50	146	2.34	308	440-volt
100	295	4.5	1,185	
150	441	6.2	2,510	
150	441	5.98	2,510	1150-volt
200	586	7.87	4,220	
300	881	11.4	9,110	
350	1028	13.3	12,370	
375	1100	14.1	14,180	
400	1173	15.2	16,180	
450	1320	17.1	20,450	
375	1100	14.7	14,220	2300-volt
400	1173	15.5	16,200	
450	1320	17.4	20,400	
500	1467	19.4	25,100	
550	1614	21.7	30,150	
600	1760	24.8	36,100	
650	1910	29.0	42,800	
700	2060	36.3	50,100	
750	2200	46.5	59,200	

Temperature of oil 70 deg. cent. Connected on low-tension for 2200 volts. (See Fig. 7.)

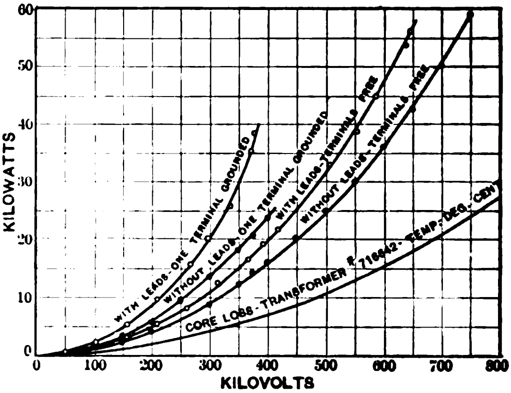

FIG. 7—NO-LOAD LOSSES, TEMPERATURE 70 DEG. CENT., 500-KV-A., 750,000-VOLT TRANSFORMER, NO. 630263
See Tables XIV to XIX.
Shows core loss of transformer No. 716642 at 19 deg. cent.)

TABLE XV

NO-LOAD LOSSES—WITHOUT LEADS AND WITH ONE HIGH-TENSION TERMINAL GROUNDED

TRANSFORMER 60 CYCLES, 500 KV-A., 1100/2200 TO 750,000 VOLTS. NO. 630,263

Kilovolts high-tension by ratio	Volts low-tension	Amperes low-tension	Watts	Current high-tension to ground	Generator connection
		Left hand leg, facing high-tension, grounded			
50	146	3.29	416	—	440-volt
100	292	7.58	1,526	—	
150	442	11.9	3,500	—	
150	442	12.3	3,490	—	1150-volt
200	588	16.5	5,980	0.053	
250	732	20.9	9,240	0.084	
300	881	25.1	13,510	0.091	
350	1028	29.1	18,390	0.107	
375	1100	31.2	20,900	0.115	
400	1175	32.8	23,800	0.122	
450	1320	Arcs to ground			
		Right hand leg, facing high-tension, grounded			
300	881	26.1	13,820	0.093	1150-volt
350	1028	30.3	18,900	—	
375	1100	32.3	21,400	0.112	
400	1173	34.7	24,600	0.118	
425	1247	Arcs to ground			

Temperature of oil 70 deg. cent. (See Fig. 7)

Some tests were also made on a companion transformer, No. 716642, which is identical to the transformer just described except that the low-tension voltage is 2500. The loss was first measured with the low-tension coils only on core, thus giving the core loss alone. The high-tension coils were then assembled on core, but left totally disconnected from each other. This high-tension winding consists of 134 coils, with a total of 26,000 turns. The volts per coil are about 2850 and the volts per layer 28½. The loss in each case was measured on the low side, and is therefore the core loss plus the dielectric loss. It is evident that the greater part of the dielectric loss is present, even with all the coils disconnected.

TABLE XVI

NO-LOAD LOSSES—WITHOUT LEADS AND WITH MIDDLE OF HIGH-TENSION WINDING GROUNDED

TRANSFORMER 60 CYCLES, 500 KV-A., 1100/2200 to 750,000 VOLTS. NO. 630,263

Kilovolts high-tension by ratio	Volts low-tension	Amperes low-tension	Watts	Generator connection
50	146	2.35	313	440-volt
100	295	4.44	1,240	
150	441	6.30	2,550	
150	441	6.03	2,520	1150-volt
200	586	7.94	4,280	
250	732	9.78	6,520	
300	881	11.7	9,300	
350	1028	13.5	12,590	
375	1100	14.3	14,310	
400	1173	15.2	16,300	
450	1320	17.0	20,700	
500	1467	18.8	25,700	
300	881	12.0	9,230	2300-volt
350	1028	13.8	12,510	
375	1100	14.8	14,220	
400	1173	15.4	16,320	
450	1320	17.2	20,500	
500	1467	19.1	25,250	
550	1614	21.7	30,800	
600	1760	24.8	36,700	
650	1910	29.4	43,100	
700	2060	36.8	50,400	
750	2200	45.7	59,300	

Temperature of oil 70 deg. cent.

TABLE XVII

NO-LOAD LOSSES—LEADS CONNECTED AND HIGH-TENSION WINDING UNGROUNDED

TRANSFORMER 60 CYCLES, 500 KV-A., 1100/2200 TO 750,000 VOLTS. NO. 630,263.

Kilovolts high-tension by ratio	Volts low-tension	Amperes low-tension	Watts	Generator connection
52.2	153	2.73	415	440-volt
104.4	306	5.29	1,560	
157.0	460	8.14	3,360	
157	460	7.92	3,270	1150-volt
209	613	10.7	5,540	
261	766	13.2	8,320	
314	920	15.8	12,500	
367	1074	18.3	16,600	
392	1150	19.5	19,050	
418	1226	20.9	22,700	
506	1484	25.1	33,000	1535-volt
554	1625	27.0	38,800	
586	1720	29.0	44,900	
636	1864	32.4	53,700	
646	1895	33.2	56,100	

Temperature of oil 70 deg. cent. (See Fig. 7)

TABLE XVIII

NO-LOAD LOSSES—LEADS CONNECTED AND ONE HIGH-TENSION TERMINAL GROUNDED

TRANSFORMER 60 CYCLES, 500 KV-A., 1100/2200 TO 750,000 VOLTS. NO. 630,263.

Kilovolts high-tension by ratio	Volts low-tension	Amperes low-tension	Watts	Generator connection
52.2	153	5.19	638	440-volt
104.4	306	11.4	2,470	
157	460	18.1	5,550	
157	460	18.7	5,450	1150-volt
209	613	25.1	9,820	
266	772	32.7	15,700	
297	875	37.2	20,100	
335	982	41.9	25,700	
370	1087	46.1	35,400	
376	1102	47.5	38,300	

Temperature of oil 70 deg. cent. (See Fig. 7)

TABLE XIX

NO-LOAD LOSSES—LEADS CONNECTED AND MIDDLE OF HIGH TENSION WINDING GROUNDED

TRANSFORMER 60 CYCLES, 500 KV-A., 1100/2200 to 750,000 VOLTS. NO. 630,263

Kilovolts high-tension by ratio	Volts low-tension	Amperes low-tension	Watts	Generator connection
177.5	497	8.91	3,350	1150-volt
327	916	16.9	11,420	
333	978	18.5	13,010	
417	1222	24.4	20,870	
502	1472	28.45	30,600	

Temperature of oil 70 deg. cent.

The transformer was next tested completely assembled and ready for service. The difference between this loss and the core loss, we may take as the dielectric loss under normal conditions. Another set of readings was taken with one high-tension terminal grounded. These curves are plotted in Fig. 8, and the readings are given in Tables XX to XXIII, inclusive.

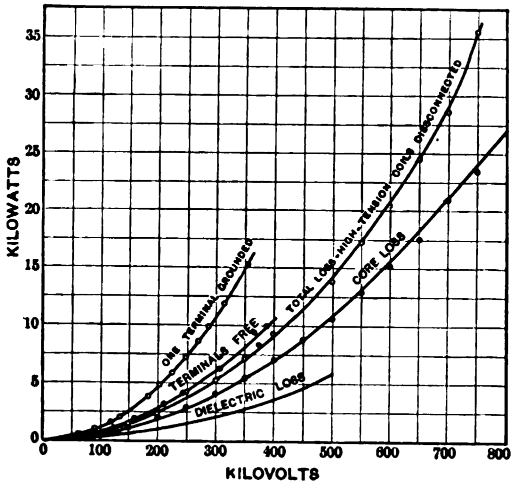

FIG. 8—NO-LOAD LOSSES, 500-KV-A., 750,000-VOLT TRANSFORMER, No. 716642

See Tables XX to XXIII.

For comparison the core loss curve of Fig. 8 is reproduced in Fig. 7. The difference between the total loss curves of Fig. 7 and the core loss curve is greater than the difference between the same curves of Fig. 8, due to the higher temperature in the first case.

TABLE XX
CORE LOSS—LOW-TENSION COILS ONLY ON CORE
TRANSFORMER 60 CYCLES, 500 KV-A., 2500 TO 750,000 VOLTS. NO. 716,642.

Low-tension volts	Kilovolts high-tension by ratio	Amperes low-tension	Watts	Generator connection
166	50	2.24	165	440-volt
333	100	3.04	607	
499	150	3.70	1,234	
499	150	3.71	1,234	1150-volt
666	200	4.35	2,025	
833	250	4.95	3,030	
1000	300	5.64	4,180	
1166	350	6.45	5,360	
1166	350	5.45	5,350	1535 volt
1335	400	7.29	7,070	
1500	450	8.34	8,830	
1670	500	9.45	10,550	
1835	550	11.5	12,900	
1835	550	11.5	12,900	2300-volt
2000	600	13.7	15,150	
2165	650	17.0	17,760	
2330	700	21.5	20,950	
2500	750	27.5	23,600	
2680	804	37.4	28,100	

Temperature of air 19 deg. cent. (See Fig. 8)

TABLE XXI
NO-LOAD LOSSES—HIGH-TENSION COILS ALL DISCONNECTED
TRANSFORMER 60 CYCLES, 500 KV-A., 2500 TO 750,000 VOLTS. NO. 716,642

Low-tension volts	Kilovolts high-tension by ratio	Amperes low-tension	Watts	Generator connection
166.5	50	2.36	196.5	440-volt
333	100	3.30	720	
500	150	4.08	1,520	
666	200	4.84	2,480	
666	200	4.80	2,470	1150-volts
833	250	5.66	3,790	
1000	300	6.54	5,280	
1165	350	7.60	7,100	
1334	400	9.00	9,550	
1250	375	8.37	8,430	2300-volt
1334	400	8.79	9,210	
1500	450	10.4	11,350	
1666	500	12.2	13,800	
1835	550	14.3	17,250	
2000	600	17.2	20,660	
2170	650	20.7	24,560	
2330	700	25.0	28,710	
2500	750	30.7	35,720	

Temperature of air 19 deg. cent. (See Fig. 8)

TABLE XXII

NO-LOAD LOSSES—TERMINALS FREE FROM GROUND

TRANSFORMER 60 CYCLES, 500 KV-A., 2500 TO 750,000 VOLTS. NO. 716,642

Low-tension volts	Kilovolts high-tension by ratio	Amperes low-tension	Watts	Generator connection
200	60	1.66	322	384-volt
242	72.5	2.02	466	
252	75.5	2.11	500	
292	87.5	2.55	648	
314	94.2	2.7	748	
324	97.2	2.91	791	
346	104	3.18	900	
420	126	3.99	1250	767-volt
540	162	5.28	1965	
705	212	7.1	3160	
762	229	7.86	3662	
814	244	8.35	4145	
823	247	8.5	4120	1150-volt
1026	308	10.7	6360	
1223	366	13.0	8830	
1291	388	13.7	9860	

Temperature of air 25.5 deg. cent. (See Fig. 8)

TABLE XXIII

NO-LOAD LOSSES—ONE HIGH-TENSION TERMINAL GROUNDED

TRANSFORMER 60 CYCLES, 500 KV-A., 2500 to 750,000 VOLTS. NO. 716,642

Low-tension volts	Kilovolts high-tension by ratio	Amperes low-tension	Watts	Generator connection
212	63.6	4.71	524	384-volts
255	76.5	6.06	740	
312	93.6	7.60	1,102	
400	120.0	10.2	1,740	
455	136.5	11.85	2,235	
608	182.5	16.4	3,880	767-volts
675	202.0	18.5	4,890	
750	225.0	20.8	5,950	
825	248.0	23.3	7,250	
758	228	21.3	6,080	1150-volts
900	270	26.3	8,720	
960	288	28.5	9,860	
1050	315	31.0	11,900	
1180	354	35.5	15,300	

Temperature of air 22.5 deg. cent. (See Fig. 8)

As the insulation losses in all cases are included in the no-load readings, no especial determination of them is necessary, but it is apparent that it is essential to measure the no-load losses at the operating temperature.

III RECOMMENDATIONS

It is recommended that Sections 156 to 159 of the Standardization Rules be amended as follows:

The losses in **TRANSFORMERS** are:

1 NO-LOAD LOSSES, including **CORE** LOSS and **DIELECTRIC** LOSS, measured with open secondary circuit, at rated frequency and rated voltage minus $I r$, where I = rated current, and r = resistance of primary circuit. There is also a small resistance loss due to exciting current in the primary.

a. CORE LOSS, including hysteresis loss and loss due to eddy currents in the steel.

b. DIELECTRIC LOSS, energy loss in the insulation due to electrostatic stress.

2 LOAD LOSSES, including **RESISTANCE** LOSS and **STRAY** LOSS, practically equal to the impedance losses which are determined by short-circuiting the secondary and impressing upon the primary *a* voltage sufficient to send rated load current through the transformer.

a. RESISTANCE LOSS, the sum of the $I r$ losses in the primary and secondary windings of a transformer, or in the two sections of the winding of an auto-transformer, where I = rated load current in the winding or section of winding, and r = resistance. In the primary, I = resultant of load current and exciting current.

b. **STRAY** LOSS, the eddy current loss in the copper, and the stray losses in the neighboring iron, due to the stray or leakage flux caused by the current at rated load.

3 On account of the variation with temperature, all losses should be measured at the operating temperature.

METHODS OF DETERMINING TEMPERATURE OF TRANSFORMERS

BY

W. M. McCONAHEY and C. FORTESCUE

Presented under the auspices of the

Standards Committee

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METHODS OF DETERMINING TEMPERATURE OF TRANSFORMERS

BY W. M. MCCONAHEY AND C. FORTESCUE

ABSTRACT OF PAPER

I. Temperature in electrical apparatus is an important factor. It affects the life of the apparatus.

II. Temperature of transformers is affected by room temperature, circulation of air, design of case and arrangement of coils. Each part of apparatus should be ventilated according to its individual requirements.

III. Discussion of tests to determine efficiency of cooling. Rules are given for determining approximately the maximum temperature of the windings.

IV. Standard methods of loading transformers are described. The direct loading method is rarely used, on account of the expense involved. The artificial methods at present in use are applicable only when two or more similar transformers are available.

V. The alternate open-circuit and short-circuit method is described. It is useful when there is only one transformer on order. Theoretical proof of the method is given.

VI. Tests are made by the new method on both self-cooled and water-cooled transformers. These tests are found to agree closely with results obtained with standard tests.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26–28, 1913.

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METHODS OF DETERMINING TEMPERATURE OF TRANSFORMERS

BY W. M. McCONAHEY AND C. FORTESCUE

I. INTRODUCTION

Temperature in most electrical apparatus plays an important part in the question of satisfactory operation. It affects not only the working efficiency but also the life of the apparatus, since the fibrous materials of which the greater part of the insulation is composed soon deteriorate under high temperatures. There is perhaps no other factor of such importance to satisfactory operation which is so difficult to measure accurately, and also is influenced to such an extent by external conditions, as the temperature of electrical apparatus under load.

This paper will give a brief discussion of conditions that affect the operating temperature of transformers and the relative merits of different methods of measuring temperatures. A description will be given of the various methods of loading, and a comparison will be made between temperatures obtained by a new method of loading a single transformer with those obtained by the standard method of loading which requires two transformers.

II. CONDITIONS AFFECTING THE TEMPERATURE OF TRANSFORMERS

In air-cooled transformers such as those designed to operate by natural ventilation without oil the temperature is directly dependent upon that of the air in the room. Thermometers, to correctly measure the air temperature in a room, should be placed well in the open. As a general rule, about the height to be comfortably read will be right. Small apparatus may be affected in temperature by the cool stream of air near the floor of the room and it will therefore be advisable in such cases to have thermometers placed about half the height of the apparatus from the floor, in which position they will give about the proper temperature of the air that comes in contact with the transformers.

Variation in room temperature has but little effect on the temperature rise of transformers which depend on direct cooling by air, but where the air serves to cool some medium of high specific heat which in turn serves as the true cooling medium, fluctuation in the air temperature will produce apparent rises in temperature that are far from correct. The best of care should be taken to have the temperature of the air in the room in which such apparatus is tested as uniform as possible. It has been suggested that a similar transformer to that on test be placed in the room and the temperature rise of the transformer on test be based on the temperature of the idle transformer. This is an admirable way of overcoming the effect of fluctuation in air temperature and will give correct results, but it is open to the objection that an additional transformer is required.

Air-cooled and oil-insulated air-cooled transformers depend for cooling chiefly on convection currents of air and it is important, therefore, that they shall have a free circulation of air from every point and that there be enough head room to carry off the heated air.

The coils and iron in an oil-insulated transformer depend upon convection of the oil for their cooling. Ventilating ducts must therefore be well distributed among the coils in such a way that as little as possible of the winding is blanketed. The larger the transformer the more important this becomes. The rate of flow of the oil will depend upon the area of the ducts, their length, the watts per unit area of exposed surface and the viscosity of the oil. An excellent test to determine the freedom of flow of the oil is to measure the difference of temperature between the bottom and top oil, as it enters and leaves a duct. In oil-insulated air-cooled transformers, however, a large difference between top and bottom oil does not necessarily mean constricted ducts. It may be due to poor design of the cooling case, whereby the air convection currents meet with resistance, and this in turn reacts on the flow of the oil, since the source of the head of both oil and air currents is the difference in temperature between the top and bottom of the coils themselves.

The different parts of the apparatus should be ventilated according to their individual requirements. Certain limitations due to structure prevent full advantage being taken of the characteristics of different materials in a transformer. Thus, iron loss decreases as the temperature of the iron is increased, but it is impossible to take advantage of this property of iron to any great extent. Moreover, the coils are so intimately associated with the magnetic circuit that it would ordinarily be a difficult matter to maintain them at widely differing temperatures. In oil transformers the temperature of the external surface of any part of the apparatus must necessarily be limited to a temperature less than that at which oil becomes injuriously affected, since there is always a film of oil at the surface which is held there by surface tension and moves only very sluggishly.

III. Tests for Efficiency of Cooling

The places in a transformer at which the temperature is likely to be a maximum depend largely upon the type and construction. In modern, section-wound, shell and core type transformers the ventilation should be so carefully designed that there can be no hot spots, so that the difference between the maximum and average temperature of the coils will practically be the same as the difference between the average temperature of the oil and that of the top or hot oil. Thus, if the maximum temperature of the oil in the ducts is 10 deg. higher than its average temperature, the maximum temperature of the coils will also be about 10 deg. higher than their average temperature.

In order to obtain a proper conception of the efficiency of the ventilation of a transformer it is necessary to know not only the temperature of the top oil but also that of the oil as it enters the ducts, because the average temperature of the transformer winding depends upon the average temperature of the oil and the maximum temperature of the winding depends upon the maximum temperature of the oil. There may be a large difference between the maximum and average values and it is quite possible to have a transformer which seemingly runs cool but the insulation of which will in time deteriorate on account of the high maximum temperature of the winding. In wire-wound coils great care has to be exercised in the design in order to avoid large differences in temperature between the inner and outer conductors. There is no very good method of measurement which will enable one to find the temperature gradient through the coil.

The following rule may be used to estimate its approximate value when the average temperature of the coils and oil are known:

θ_1 = Estimated value of temperature gradient through external insulation of coil.

θ_2 = Average temperature of coil above average oil

θ = Temperature gradient through coil.

$\theta = 1\tfrac{1}{2}\,\theta_2 - \tfrac{1}{2}\,\theta_1$

θ_{max} = Maximum temperature rise of oil + θ.

This formula assumes, as a matter of course, that the coils are efficiently ventilated.

Thermometers in a transformer can be used only to indicate temperatures in the coils, not to measure them. Their usefulness consists in their ability to show up anything abnormal, such as the constriction of a duct. In other words, if a thermometer indicates a winding temperature differing very much from that of the hot oil, it is an indication that there is something wrong with the ventilation at that point. It has been proposed that thermocouples be used to determine the maximum temperature of transformer coils under load. It is impossible to tell the exact location of the hottest place in a coil and it would therefore be necessary, if such a method were adopted, to place a number of couples at all the places likely to have a high temperature. It is very difficult to see how such a scheme could be used without danger both to the operator and the apparatus. The only suitable place for the application of such methods is in the laboratory where proper precautions can be taken and where the work is done by skilled operators.

The average temperature can be obtained by the resistance method. The work of measuring the resistances of the windings of an oil transformer should be done as quickly as possible because the coils, on account of their small specific heat, quickly lose their temperature above the coil. Probably the best way for measuring high resistances is by means of the Wheatstone bridge, while for low resistances the Kelvin bridge may be used. Whatever method is used, the settings of the instruments should be adjusted for the approximate values so that the time required for the final adjustment may be reduced to a minimum.

The authors are of the opinion that for commercial testing the thermometer and resistance methods of measuring temperatures should be adhered to, as by their means and with the exercise of care in making the tests the efficiency of cooling of a transformer may easily be determined.

IV. Methods of Loading Transformers for Temperature Test

Transformers may be loaded directly on resistance racks or any other means for dissipating power; or two or more of them in combination may be artificially loaded. The first method of loading, on account of the expense involved, is limited to small transformers and special transformers where there is only one on order. The second method is economical in application, flexible in operation and is by far the most satisfactory.

The methods hitherto in use for artificially loading transformers are applicable only when more than one transformer is available. They are all modifications of one scheme, which is that used for loading two single-phase transformers and is commonly referred to as the "opposition method," shown in Fig. 1. Excitation voltage may be supplied from the same circuit as the load current or it may be taken from an independent circuit of the proper frequency for the transformer. Where a large number of similar transformers are to be loaded at the same time their primary windings may be connected in parallel and their secondaries may also be connected in parallel, or the secondary of one

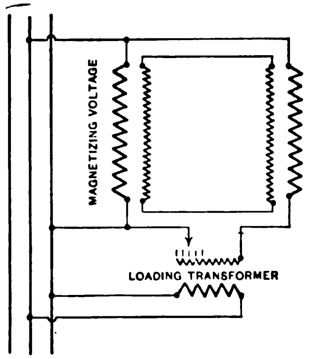

Fig. 1—Loading Scheme for Two Transformers

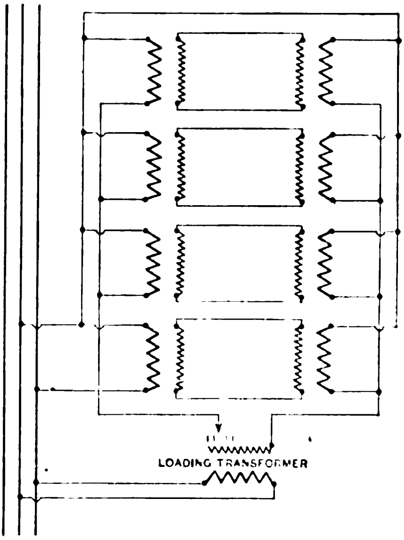

Fig. 2—Loading Scheme for More than Two Transformers

transformer in a group may be paired with that of one of the opposition group independently of the secondaries of the other transformers in the same group. (See Fig. 2). When there are

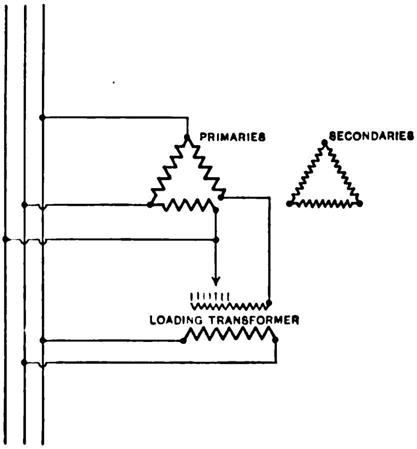

FIG. 3—SCHEME FOR THREE-PHASE LOADING

three single-phase transformers or one three-phase transformer the scheme shown in Fig. 3 may be used. The essential law to be observed in these methods when applied to polyphase loading is that the sum of the secondary induced electromotive forces

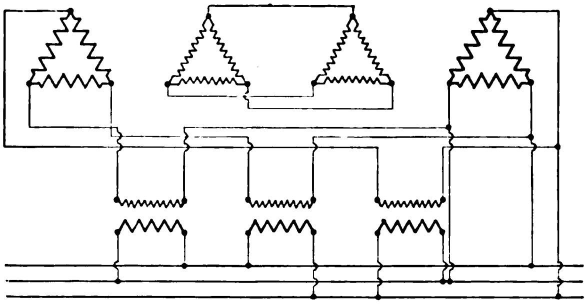

FIG. 4—SCHEME FOR THREE-PHASE BALANCED LOADING

taken around the circuit shall be zero. Six single-phase transformers or two three-phase transformers may be made to take a balanced load from a three-phase circuit by the scheme shown in Fig. 4.

V. ALTERNATE OPEN–CIRCUIT AND SHORT–CIRCUIT METHOD

The methods of loading transformers just described are applicable only when there are two or more transformers to be tested. It is sometimes necessary to test a single transformer, and it is generally impossible to obtain another suitable one to run in opposition. The following method has been devised to meet this condition.

The alternate open-circuit and short-circuit method of loading a transformer is effected by first exciting the transformer to be tested so as to obtain a core loss equal in value to the total losses of the transformer and running it on open circuit with this excitation for a fraction of a period t, previously decided upon, equal to the ratio of normal iron loss to total loss. Secondly the transformer is run on short circuit with a current in the windings of such value as to give a short-circuit loss equal to the total loss, for the remainder of the period t which is a fraction of the total period equal to the ratio of normal copper loss to total loss. The cycle is repeated until steady conditions are reached. With length of period not too great this method will give results closely approximating those obtained by the other methods.

The theoretical proof of this method is as follows: Assume that the copper is initially at the same temperature as the oil which is supposed to have reached its final value. The symbols used in this discussion and their definitions are as follows:

θ_c = Final average temperature rise of copper above average temperature of oil.

θ_1 = Average temperature rise of copper above average temperature of oil at end of first cycle.

θ_2 = Average temperature rise of copper above average temperature of oil at end of open-circuit run in second cycle.

θ_3 = Average temperature rise of copper above average temperature of oil at end of second cycle.

$\theta_{(2n-1)}$ = Average temperature rise of copper above average temperature of oil at end of *nth* cycle.

θ_{2n} = Average temperature rise of copper above oil at end of open-circuit part of $(n+1)$th cycle.

α = Emissivity of coil surface exposed to oil, in watts per sq. in. per deg.

S_c = Total surface of coil exposed to oil, in sq. in.

W = Weight of copper, in lb.

x = Time measured from start of run, in hours.
t = Period in hours.
E_c = Normal copper loss.
E_1 = Normal iron loss.
θ_a = Temperature at end of time x_1 on short-circuit.
θ_b = Temperature at end of time x_2 on open-circuit.

The value of the average rise in temperature of the coils above the average temperature of the coil is given by

$$\theta_c = \frac{E_c}{\alpha\, S_c} \tag{1}$$

With a copper loss E and measuring the time x from the instant at which the average temperature of the oil and coils are the same, the temperature rise of the coils above the oil will be

$$\theta = \frac{E}{\alpha\, S_c}\left(1 - \frac{1}{10^{\frac{8.75\, \alpha\, S_c\, x}{W}}}\right) \tag{2}$$

At the end of time x_1 we shall have

$$\theta_a = \frac{E\, \theta_c}{E_c}\left(1 - \frac{1}{10^{\frac{8.75\, E_c\, x_1}{W\, \theta_c}}}\right) \tag{3}$$

If at the end of this time x_1 the load be removed and the transformer run on open circuit the copper will cool and its temperature at the end of time x_2 will be

$$\theta_b = \frac{\theta_a}{10^{\frac{8.75\, E_c\, x_2}{W\, \theta_c}}} \tag{4}$$

Considering a cycle of period t, the length of the short-circuit portion of the period is

$$\frac{E_c}{E_c + E_f}\, t$$

The temperature rise of the coils above the average oil at the end of this time will then be

$$\theta_1 = \frac{(E_c + E_f)\,\theta_c}{E_c}\left(1 - \frac{1}{10^{\frac{8.75\,E_c^2\,t}{W\,(E_c + E_f)\,\theta_c}}}\right)$$

or, designating $\frac{(E_c + E_f)\,\theta_c}{E_c}$ by θ_T,

$$\theta_1 = \theta_T\left(1 - \frac{1}{10^{\frac{8.75\,E_c\,t}{W\,\theta_T}}}\right)$$

similarly,

$$\theta_2 = \frac{\theta_1}{10^{\frac{8.75\,E_f\,t}{W\,\theta_T}}}$$

$$\theta_3 = \theta_T\left(1 - \frac{1}{10^{\frac{8.75\,E_c\,t}{W\,\theta_T}}}\right) + \frac{\theta_T\left(1 - \frac{1}{10^{\frac{8.75\,E_c\,t}{W\,\theta_T}}}\right)}{10^{\frac{8.75\,(E_f + E_c)\,t}{W\,\theta_T}}}$$

$$\theta_4 = \frac{\theta_3}{10^{\frac{8.75\,E_f\,t}{W\,\theta_T}}}$$

$$\theta_5 = \theta_T\left(1 - \frac{1}{10^{\frac{8.75\,E_c\,t}{W\,\theta_T}}}\right)$$

$$+ \frac{\theta_T\left(1 - \frac{1}{10^{\frac{8.75\,E_c\,t}{W\,\theta_T}}}\right)}{10^{\frac{8.75\,(E_f + E_c)\,t}{W\,\theta_T}}} + \frac{\theta_T\left(1 - \frac{1}{10^{\frac{8.75\,E_c\,t}{W\,\theta_T}}}\right)}{10^{\frac{8.75\times 2\,(E_f + E_c)\,t}{W\,\theta_T}}}$$

$$\theta_{(2n-1)} = \theta_T\left(1 - \frac{1}{10^{\frac{8.75\,E_c\,t}{W\,\theta_T}}}\right) + \frac{\theta_T\left(1 - \frac{1}{10^{\frac{8.75\,E_c\,t}{W\,\theta_T}}}\right)}{10^{\frac{8.75\,(E_f + E_c)\,t}{W\,\theta_T}}} + \dots\dots$$

$$+ \frac{\theta_T\left(1 - \frac{1}{10^{\frac{8.75\,E_c\,t}{W\,\theta_T}}}\right)}{10^{\frac{8.75\,(n-1)\,(E_f + E_c)\,t}{W\,\theta_T}}} \qquad (5)$$

$$\theta_{2n} = \frac{\theta_{(2n-1)}}{10^{\frac{8.75\,E_f\,t}{W\,\theta_T}}} \qquad (6)$$

The expansion for θ_{2n-1} is a geometrical progression which is convergent, hence we have

$$\theta_{(2\infty-1)} = \frac{\theta_T\left(1 - \frac{1}{10^{\frac{8.75\,E_c\,t}{W\,\theta_T}}}\right)}{1 - \frac{1}{10^{\frac{8.75(E_c+E_f)t}{W\,\theta_T}}}} \qquad (7)$$

$$\theta_{2\infty} = \frac{\theta_{(2\infty-1}}{10^{\frac{8.75\,E_f\,t}{W\,\theta_T}}} \qquad (8)$$

If the length of the period t be made exceedingly small,

$$\theta_{2\infty-1} = \theta_{2\infty} = \theta_T\,\frac{E_c}{E_c + E_f} = \theta_c \qquad (9)$$

Hence, for very small periods the final value is the same as that obtained under normal load conditions. It remains to be seen how much of an error is caused by the length of the period t being finite.

Let us apply this to an actual case of a 150-kv-a. transformer. In this transformer.

$$\begin{aligned} E_f &= 1390 \text{ watts} \\ E_c &= 1136 \text{ watts} \\ (E_f + E_c) &= 2526 \text{ watts} \\ \theta_c &= 17 \text{ deg.} \\ \theta_T &= 37.8 \text{ deg.} \\ W &= 270 \text{ lb.} \\ t &= \tfrac{1}{2} \text{ hr.} \end{aligned}$$

$$\frac{8.75\, E_f\, t}{W\, \theta_T} = 0.596 \qquad 10^{\frac{8.75\, E_f\, t}{W\, \theta_T}} = 3.945$$

$$\frac{8.75\, E_c\, t}{W\, \theta_T} = 0.486 \qquad 10^{\frac{8.75\, E_c\, t}{W\, \theta_T}} = 3.062$$

$$\frac{8.75\, (E_c + E_f)\, t}{W\, \theta_T} = 1.082 \qquad 10^{\frac{8.75\, (E_c + E_f)\, t}{W\, \theta_T}} = 12.08$$

$$\begin{aligned} \theta_{(2\infty - 1)} &= 28.5 \text{ deg.} \\ \theta_{2\infty} &= 7.2 \text{ deg.} \end{aligned}$$

The average of these two is 17.85 deg., which is close enough to the correct value $\theta_c = 17$ deg.

For a period $t = \frac{1}{4}$ hr.

$$\begin{aligned} \theta_{(2\infty - 1)} &= 23.3 \text{ deg.} \\ \theta_{2\infty} &= 11.74 \text{ deg.} \\ \text{Average} &= 17.52 \text{ deg.} \\ \theta_c &= 17.00 \text{ deg.} \end{aligned}$$

Evidently in this particular case there is very little to be gained in accuracy by making the period t less than one-half hour. In transformers which have high copper loss as compared with iron loss it may be found necessary to use a period of less than one-half hour.

VI.—TEMPERATURE TESTS ON TRANSFORMERS BY THE ALTERNATE OPEN-CIRCUIT AND SHORT-CIRCUIT METHOD

Tests were made on a 150-kv-a. 60-cycle oil insulated air-cooled transformer to obtain a comparison between this method and the standard opposition method. The results of the various tests made indicate a good check between the two methods. The transformers chosen agreed closely in characteristics, but in order to eliminate any error due to possible differences between them they were interchanged in the second run. The following are the principal values taken from the test results for the purpose of comparison. The thermometer readings were taken at the middle of the short-circuit part of the cycle. The temperature rises by resistances are a mean between those obtained at the beginning and end of the short-circuit part of the cycle.

TEMPERATURE RISES AT FULL LOAD AFTER STEADY CONDITION WERE REACHED

	Opposition method	Alternate short-circuit and open-circuit method
Temperature rise of low-tension coils by thermometer	38.5	37
Temperature rise of high-tension coils by thermometer	33.5	35
Temperature rise of top oil	31.5	32
Temperature rise of bottom oil	10.5	11

RISE OF TEMPERATURE OF WINDING BY RESISTANCE

	Opposition method	Alternate short-circut and open-circuit method
High-tension	33.9	34.6
Low-tension	40.7	41.5

These results are seen to be in very close agreement. The readings obtained on a second run with the two transformers interchanged are as follows:

TEMPERATURE RISES AT FULL LOAD AFTER STEADY CONDITIONS WERE REACHED

	Opposition method	Alternate open-circuit and short-circuit method
Temperature rise of low-tension coils by thermometer	35	36
Temperature rise of high-tension coils by thermometer	34	32
Temperature rise of top oil	29	30
Temperature rise of bottom oil	9	10

TEMPERATURE RISE MEASURED BY INCREASE OF RESISTANCE.

	Opposition method	Alternate open-circuit and short-circuit method
High-tension	33	34.4
Low-tension	39	41.0

All the results cited above were taken with a 30-minute period. The following rises by resistance were taken with a 15-minute period.

TEMPERATURE RISE MEASURED BY INCREASE OF RESISTANCE.

	Opposition method	Alternate open-circuit and short-circuit method
High-tension	33	33.3
Low-tension	39	39.6

A third test at 125 per cent load was made on the same transformers for temperature rises by the resistance method, with the following results.

TEMPERATURE RISE AT 125 PER CENT LOAD, MEASURED BY INCREASE OF RESISTANCE METHOD

	Opposition method	Alternate open-circuit and short-circuit method
High-tension	43	42.6
Low-tension	53	53.3

This method was also tried on a 2500-kv-a. water-cooled transformer, in comparison with the opposition method, the same flow of water being used in each case. The length of period was 15 minutes. The results were:

TEMPERATURE RISE ABOVE COLD WATER

	Opposition method	Alternate open-circuit and short-circuit method
High-tension	41.1	41.1
Low-tension	39.5	39.4

The tests were run a second time with the same results.

The results given indicate that the method of alternate short-circuit and open-circuit, as carried out, gives a very close approximation to the conditions of temperature obtained under load.

DETERMINATION OF LOAD LOSS CORRECTION FACTORS FOR ROTATING ELECTRIC MACHINES

BY

E. M. OLIN and S. L. HENDERSON

Presented under the auspices of the

Standards Committee

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DETERMINATION OF LOAD LOSS CORRECTION FACTORS FOR ROTATING ELECTRIC MACHINES

BY E. M. OLIN AND S. L. HENDERSON

Abstract of Paper

The paper describes tests which have been made to determine load loss correction factors for direct-current motors and generators, alternating-current generators and synchronous motors, and synchronous converters. The term " load loss " is understood to mean the difference between the total losses under load and the sum of the separate losses as determined from no-load measurements. A series of very careful loss measurements, made with conditions equivalent to those normally existing under load, is described. The losses thus measured are the sum total of the individual losses under load. These values are compared with the sum of the separate losses as determined from no load measurements. The difference between the readings is the " load loss " or " stray loss."

This load loss is due, first, to the increased core loss resulting from field distortion, second, to eddy current losses in the armature conductors caused by fields set up by useful currents flowing in them. All the other losses can be accurately determined from no load measurements. Therefore the proposed correcting factors are not to be applied to the sum of the separate losses but to the sum of the calculated armature I^2r loss and the no load core loss.

A few laboratory tests on the different types indicate certain fairly uniform ratios existing between the sum of these losses under actual load conditions and their sum as determined from no load measurements.

A large number of commercial input-output tests is then examined and checked by means of the correcting factors determined from these laboratory tests. As the averages of the commercial tests agree quite closely with the laboratory tests the authors feel justified in recommending the following values for the proposed correction factors.

	Value of constant.			
Fractional loads........	2/4	3/4	4/4	5/4
Direct-current generator...........				
Direct-current motor...............	1.1	1.2	1.3	1.4
Alternating-current generator Synchronous motor — *Stranded... conductors...	1.01	1.03	1.10	1.2
†Synchronous converter 60 cycles	1.04	1.07	1.10	1.2
All Synchronous converters 25 cycles	1.0	1.0	1.0	1.0

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*Does not apply to machines with deep strap conductors in which the eddy current loss in the copper may be large.

†Non- commutating pole type. Tests on commutating pole type not completed.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26–28, 1913.

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(*Subject to final revision for the Transactions.*)

DETERMINATION OF LOAD LOSS CORRECTION FACTORS FOR ROTATING ELECTRIC MACHINES

BY E. M. OLIN AND S. L. HENDERSON

It is well known that certain of the losses occurring in rotating electric machines can be accurately determined from no-load measurements. Some of the losses, however, cannot be so determined, as, owing to conditions which develop, as load is applied, a gradual increase in these losses takes place.

The difference between the total losses under load and the sum of the separate losses as determined from no-load measurements is commonly known as " load loss " or " stray loss."

This paper will present data relating to the load losses of certain classes of machines and will describe the methods employed to secure the data.

The classes considered are the following.

a. Direct-current motors and generators.

b. Alternating-current generators and synchronous motors.

c. Synchronous converters.

At any given load the only losses occurring in these types which cannot be accurately determined from no-load measurements are the so-called " core loss " and the loss due to eddies set up in the armature conductors by the stray fields of useful currents flowing in these conductors.

In a paper* previously prepared by one of the present writers it was proposed to apply empirical correcting factors to the values of core loss and armature copper loss as determined from no-load measurements in order to arrive at their true values under load.

**Determination of Power Efficiency of Rotating Electric Machines*, E. M. Olin, PROCEEDINGS, A. I. E. E., July, 1912, p. 1287.

Two constants were suggested, the first to be applied to the measured no-load core loss to compensate for the increased loss due to field distortion under load, the second to be applied to the calculated armature I^2r loss to compensate for eddies in the conductors due to the application of load. These eddies include the secondary losses of commutation as well as those set up by useful currents flowing in the conductors.

Since that paper was written tests have been conducted with a view to establishing the values of these constants. Very early during the progress of these tests it was found that it would not be practicable to separate the increased loss due to load into its two component parts, namely the increase in core loss due to field distortion, and the increase in copper loss due to eddies in armature conductors.

In other words, two separate constants could not be determined, as no satisfactory method could be worked out for arriving at their values. It was found, however, that in each type of machine a fairly uniform ratio exists between the sum of these losses as determined from no-load measurements and their sum as determined from actual load tests.

This relation may be expressed thus: At any given load,

$$\begin{aligned}&\textit{actual core loss} + \textit{actual armature copper loss}\\ &= \lambda\,(\textit{measured no-load core loss} + \textit{calculated armature } I^2r \textit{ loss}),\end{aligned}$$

where λ is a constant depending upon the type of machine and upon the magnitude of the load.

In order to determine the values for this constant, special tests were conducted on each type of machine. In these tests every possible refinement was employed. The most approved methods were used, and the most expert men. All instruments were specially calibrated and great care was used to locate them where they would not be influenced by stray fields. To avoid fluctuations special machines were used to generate the power. Each reading is the average of a series of ten readings taken at intervals of ten seconds. These tests will be referred to throughout as " laboratory " tests to distinguish them from the ordinary commercial tests recorded herein, a large number of which were examined with a view to further checking the values for the constants.

DIRECT-CURRENT MACHINES

A convenient way of determining the load losses of direct-current generators or motors is by measuring the power supplied from outside sources to a pair of coupled machines loaded one against the other by the well known " pumping back " method. In this test the shafts of two similar machines are rigidly coupled together mechanically, the armatures are connected in parallel electrically and current is made to flow between them by adjusting the field strengths to get the required difference in e.m.f's.

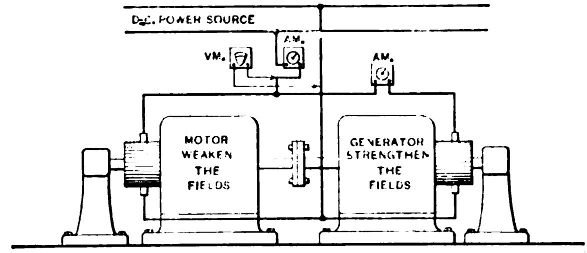

FIG. 1—" LOADING-BACK " TEST OF DIRECT-CURRENT MACHINES—LOSSES SUPPLIED ELECTRICALLY

There are two ways of making the test. In one the losses are supplied by direct electrical connection to the armature circuit of the machines under test, as in Fig. 1; in the other the losses are supplied mechanically by means of a calibrated driving motor, as in Fig. 2.

In either case the power supplied from outside sources represents the combined losses of the two machines. By a comparison of these losses with the separate losses as calculated from no-load measurements, the increased loss under load due to field distortion and eddies in armature conductors can be determined. If possible, machines exactly alike in characteristics should be used to get the best results.

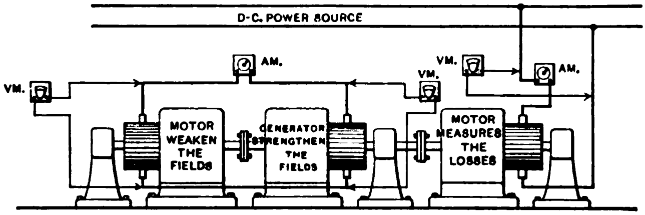

FIG. 2—" LOADING-BACK " TEST OF DIRECT-CURRENT MACHINES—LOSSES SUPPLIED MECHANICALLY

Referring to Fig. 1, it is to be noted that the machine which operates as a motor will take a greater armature current than that operating as a generator by the amount of loss current supplied from the outside source. Due allowance must be made for this when computing the separate losses. The internal voltage of each machine is calculated at any load from the known armature current flowing, the resistance of windings and brushes and the known terminal voltage.

The no-load core loss of each machine corresponding to these internal voltages is found by referring to core loss characteristics previously determined by the separate driving motor method. The I^2r losses are computed from the measured resistances and the known current flowing in each machine. The frictional losses can be measured by the separate driving motor method or computed from a comparison of the no-load power input reading and the core loss characteristics.

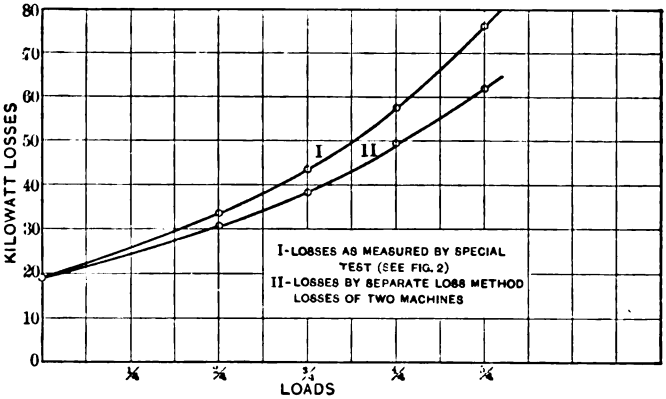

FIG. 3—470-H.P., 500-VOLT D-C. MOTOR, COMMUTATING POLE, 415 REV. PER. MIN.

When the losses are supplied mechanically, as shown in Fig. 2, the same current circulates in the armature circuit of each machine, but the internal voltages are somewhat different. The separate losses are computed as before.

Laboratory tests were conducted on a pair of 470-h.p. direct-current commutating-pole motors of the most modern design, according to the method described above, with the losses supplied mechanically as shown in Fig. 2. The results of this test are shown in Fig. 3, and in Table I.

In addition to the test described above, the readings taken on

TABLE I

LABORATORY TESTS DETERMINATION OF CONSTANT λ—DIRECT-CURRENT MACHINES

Values for two machines								Values for one machine	
Machine	Fractional loads	*A* Losses supplied by driving motor kw.	*B* Total losses from no-load readings kw.	*C* Load loss $A - B$ kw.	*D* No-load core loss kw.	*E* Calculated armature I^2r loss kw.	λ $\frac{C + D + E}{D + E}$	Efficiencies by separate losses: Without constant λ	Efficiencies by separate losses: With constant λ
470 h.p. motors, 550 volts	2/4	33.1	30.96	2.04	13.7	4.22	1.11	91.4	90.9
commutating pole 415 rev. per min.	3/4	43.15	38.57	4.58	14.0	8.61	1.20	92.3	91.6
(See Fig. 2)	4/4	57.3	49.34	7.96	13.85	15.34	1.27	92.8	91.7
for special test	5/4	76.2	61.44	13.76	13.75	23.43	1.37	92.5	91.1

a pair of 3750-kw. commutating-pole generators which happened to be on the test floor at the same time, were carefully gone over with a view to getting further information as to the values of the constant.

These generators were tested by the " pumping back " method with electrical loss supply, as shown in Fig. 1. Conditions were not as favorable as in the case of the 470-h.p. motors, owing to fluctuations of the power circuit supplying the losses, due partly to the inertia of the heavy rotors. Hence we have not termed this a " laboratory " test. Nevertheless, fairly satisfactory readings were obtained at full load and the value of the correction factor was found to be 1.32.

A number of commercial input-output tests were then examined. Some of these were of motors, with the mechanical output measured by Prony brake. Others were of motor-generators, where both input and output were measured electrically. The input-output efficiency was in each case checked against the efficiency by separate losses corrected by the factor λ using values of this constant as found in the tests just described. Table II shows the results of this comparison.

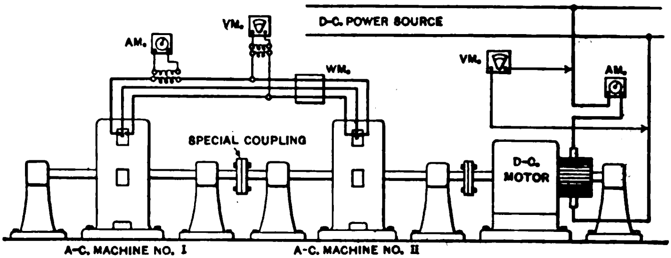

FIG. 4—" LOADING-BACK " TEST OF ALTERNATING-CURRENT MACHINES

ALTERNATING-CURRENT MACHINES

The load losses of alternating-current generators and synchronous motors may be conveniently arrived at as follows: Two machines made from the same specifications (and therefore of the same wave form) are rigidly connected together and driven from a calibrated motor, as shown in Fig. 4. The rigid connection between the a-c. machines is made by means of a special coupling so arranged that the position of the rotating elements with respect to each other can be varied. There will be certain positions of the rotors when the armature circuits can be paralleled

TABLE II

DIRECT-CURRENT MACHINES—COMMERCIAL TESTS

Machine	Fractional loads	*A* Core loss at no-load	*B* Calculated armature I^2r loss	λ as determined by special test	λ $(A + B)$	Total losses from no-load readings		Kilowatts output or input	Efficiency by losses		Efficiency by input-output
						Without correction factor	With correction factor λ		Without correction factor	With correction factor	
* 30-h.p., 230-volt, 975 rev. per min. d-c. commutating pole motor	2/4	0.433	0.155	1.1	0.646	1.64	1.70	12.97	87.4	86.7	86.3
	3/4	0.428	0.310	1.2	0.885	1.95	2.10	19.06	89.8	89.1	88.2
	4/4	0.418	0.552	1.3	1.26	2.31	2.60	25.08	90.7	89.6	89.2
	5/4	0.405	0.856	1.4	1.74	2.82	3.30	31.12	90.9	89.4	89.8
*35-h.p., 230-volt, 1150 rev. per min. d-c. commutating pole motor	2/4	0.783	0.150	1.1	1.081	2.02	2.07	15.60	87.0	86.2	83.7
	3/4	0.770	0.322	1.2	1.205	2.4	2.55	22.70	89.4	88.5	86.3
	4/4	0.755	0.572	1.3	1.72	2.77	3.16	29.70	90.6	89.3	87.9
	5/4	0.740	0.892	1.4	2.28	3.35	4.00	36.80	91.0	89.3	88.8
*60-h.p., 230-volt, 650 rev. per min. d-c. commutating pole motor	2/4	1.50	0.134	1.1	1.8	3.57	3.74	25.96	86.4	85.6	86.3
	3/4	1.48	0.29	1.2	2.12	3.90	4.25	28.10	89.8	88.9	88.2
	4/4	1.46	0.50	1.3	2.55	4.32	4.91	50.20	91.4	90.1	89.2
	5/4	1.44	0.765	1.4	3.08	5.75	6.63	62.0	92.3	90.8	90.2
†160-kw., 400-volt, 750 rev. per min. d-c. commutating pole generator	4/4	1.98	4.39	1.3	8.28	12.16	14.07	160.0	93.0	92.0	92.3
†260-h.p., 550-volt, 750 rev. per min. d-c. commutating pole motor	4/4	3.25	3.14	1.3	8.30	12.00	13.91	187.0	93.5	92.6	92.8
†175-kw., 550-volt, 600 rev. per min. d-c. commutating pole generator	5/4	8.5	4.11	1.4	17.63	19.71	24.73	219	91.7	90.0	89.5

TABLE II—*Continued.*

Machine	Fractional loads	*A* Core loss at no-load	*B* Calculated armature I^2r loss	λ as determined by special test	$\lambda\ (A + B)$	Total losses from no-load readings		Kilowatts output or input	Efficiency by losses		Efficiency by input-output
						Without correction factor	With correction factor λ		Without correction factor	With correction factor	
†260-h.p., 220-volt, 600 rev. per min. d-c. commutating pole motor	5/4	2.4	9.26	1.4	16.30	21.74	26.38	271.8	92.0	90.3	90.0
200-kw. syn. conv., as direct-current generator, 575-volt, three-phase, 60 cycles, 1200 rev. per min. (See Fig. 12.)	2/5	8.05	0.50	1.09	9.32	15.7	16.5	85.1	84.5	83.9	84.0
	2/4	8.10	0.97	1.10	10.1	16.7	17.7	112.5	87.1	86.4	86.5
	3/4	8.20	1.70	1.20	11.88	17.8	19.8	148.0	89.4	88.3	88.5
	4/4	8.30	2.60	1.30	13.73	19.0	21.8	183.1	90.5	89.3	89.3
	5/4	8.35	3.58	1.30	15.75	20.2	24.0	214.5	91.4	90.0	89.7
*20-h.p., 230-volt, 650 rev. per min. d-c. commutating pole motor	2/4	0.244	0.166	1.1	0.451	1.15	1.19	8.76	86.9	86.3	85.2
	3/4	0.240	0.39	1.2	0.756	1.45	1.58	12.77	88.7	87.7	87.6
	4/4	0.230	0.685	1.3	1.19	1.85	2.03	17.00	89.2	87.5	87.9
	5/4	0.218	1.044	1.4	1.70	2.45	2.89	21.50	88.7	86.2	86.9
*20-h.p., 115-volt, 650 rev. per min. d-c. commutating pole motor	2/4	0.270	0.166	1.1	0.48	1.36	1.40	8.87	84.7	84.1	84.1
	3/4	0.263	0.374	1.2	0.765	1.64	1.77	13.04	87.3	86.5	85.8
	4/4	0.248	0.674	1.3	1.20	2.12	2.40	17.0	87.7	86.2	86.3
	5/4	0.230	1.05	1.4	1.791	2.83	3.34*	21.73	87.0	84.8	85.9
*25-h.p., 115-volt, 825 rev. per min. d-c. commutating pole motor	2/4	0.450	0.151	1.1	0.662	1.65	1.71	11.23	85.3	84.6	83.0
	3/4	0.440	0.236	1.2	0.881	2.0	2.18	16.38	87.8	86.9	85.4
	4/4	0.420	0.591	1.3	1.314	2.55	2.85	21.75	88.4	87	85.7
	5/4	0.400	0.956	1.4	1.898	3.23	3.77	27.36	88.3	86.4	85.1
3750-kw., 275-volt, commutating pole d-c. generator 180 rev. per min. (See Fig. 1.)	4/4	50.0	65.8	1.3	150.5	239.9	274.6	3750	94.0	93.2	

* Mechanical output by Prony brake. † Part of motor-generator.

without a flow of cross currents between the machines, in other words, when a condition of synchronism exists. If now the two rotors are shifted slightly with respect to each other, current will tend to flow between the machines, depending in amount on the degree of angular displacement between the rotors.

Any desired load, at practically unity power factor, can be obtained by this method. The power delivered at the shaft of the coupled machines by the calibrated driving motor represents their losses under load conditions.

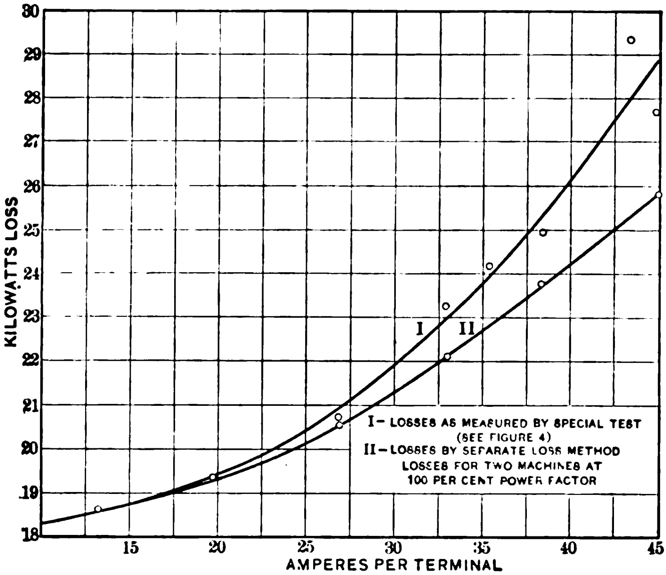

FIG. 5—ALTERNATING-CURRENT GENERATOR, 150 KV-A., 2400 VOLTS, THREE-PHASE, 60 CYCLES, 900 REV. PER. MIN.

By comparing the separate losses as computed from no-load measurements with the losses as shown in the tests described above, the increased loss due to the application of load can be determined.

The machines selected for investigation were two 150-kv-a. 2,400-volt 60-cycle belted generators built from the same specifications.

The tests were conducted as described above. (See also Fig. 4.) Laboratory methods were employed. The results are as shown in Table III and Fig. 5.

TABLE III—LABORATORY TESTS

DETERMINATION OF CONSTANT λ—ALTERNATING-CURRENT MACHINES. (SEE FIG. 4)

Machine	Fractional loads	Two machines						One machine	
		A	B	C	D	E		Efficiency by losses	
		Losses supplied by driving motor kw.	Total no-load losses kw.	Load loss = $A - B$ kw.	No-load core loss kw.	Calculated armature I^2r loss kw.	λ $\frac{C + D + E}{D + E}$	Without correcting factor	With correcting factor
150 kv-a., three-phase, 2400-volt, 60-cycle a-c. generator	2/4	19.09	19.07	0.02	8.66	1.14	1.002	88.7	88.68
	3/4	20.94	20.67	0.27	8.66	2.55	1.024	91.7	91.6
	4/4	24.19	22.97	1.22	8.66	4.55	1.092	92.9	92.5
	5/4	28.98	25.88	3.10	8.66	7.10	1.197	93.5	92.8

SYNCHRONOUS CONVERTERS

The method previously described for determining the load losses of direct- and alternating-current motors and generators are not well adapted for synchronous converters. Our experience indicates that the introduction of the necessary boosters in the armature leads complicates the situation to such an extent that the results cannot be relied upon.

For this class of machines the straight input-output method was used with the following modification. Two identical synchronous converters were used, one operating d-c. to a-c. to feed a second machine operating as a straight converter. The advantages are: 1st, the wave forms of the power circuit (the d-c. to a-c. converter) and of the other converter (the a-c. to d-c. converter) are identical. 2nd, the overall efficiency of the two synchronous converters can be computed by a comparison of the direct-current input with the direct-current output. This is an advantage, for d-c. measuring instruments are more reliable and give steadier readings than the a-c. instruments. Fig. 6 shows the scheme of connections used for this test.

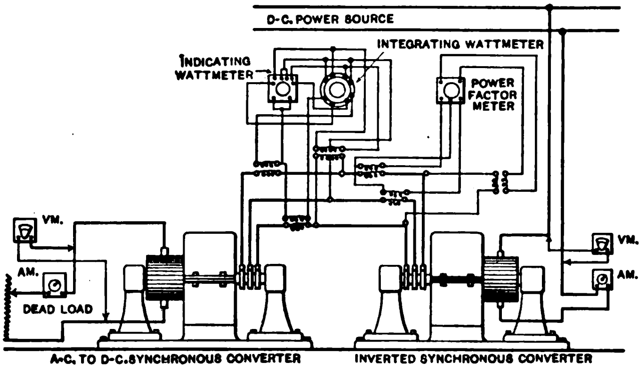

FIG. 6—INPUT-OUTPUT TEST OF SYNCHRONOUS CONVERTERS

The laboratory tests were made on 60-cycle non-commutating pole synchronous converters. Two different pairs of synchronous converters were tested and the results are shown in Tables IV and V and in Figs. 7, 8, 9 and 10. At each load, ten readings were taken at ten-sec. intervals and an average taken for each point. It will be seen that the results in the two tests check very well together and go to show that the load loss is small, up to and including full load. On the heavy over loads serious sparking at the brushes occurs and the load loss factor increases rapidly.

TABLE IV

LABORATORY TESTS—DETERMINATION OF CONSTANT λ—SYNCHRONOUS CONVERTERS

(SEE FIG. 6)

Machine	Fractional loads	*A* Losses from input-output kw.	*B* Total losses from no-load readings kw.	*C* Load loss *A* — *B* kw.	*D* No-load core loss kw.	*E* Calculated armature I^2r loss kw.	λ $\frac{C+D+E}{D+E}$ kw.	Efficiency by separate losses	Efficiency by input-output
200-kw., 625-volt, three-phase, 60 cycles 1200 rev. per min. (See Fig. 6)	2/4	13.19	13.0	0.19	4.36	0.51	1.04	88.5	88.3
	3/4	14.18	13.82	0.36	4.39	1.12	1.07	91.6	91.4
	4/4	15.6	14.9	0.70	4.41	1.99	1.10	93.1	92.9
	5/4	17.6	16.4	1.2	4.44	3.12	1.16	93.8	93.4
	6/4	20.0	17.99	2.01	4.47	4.49	1.22	94.3	93.8
200-kw., 575-volt, three-phase, 60 cycles 1200 rev. per min. (See Fig. 6)	2/4	16.35	16.03	0.32	8.0	0.43	1.04	86.2	85.9
	3/4	17.58	16.8	0.70	8.1	0.95	1.08	90.0	89.6
	4/4	19.22	17.92	1.18	8.15	1.71	1.12	91.8	91.3
	5/4	21.16	19.22	1.89	8.2	2.74	1.17	92.9	92.3
	6/4	23.2	20.73	2.47	8.3	3.84	1.25	92.5	92.8

TABLE V

LABORATORY TESTS—DETERMINATION OF CONSTANT λ—SYNCHRONOUS CONVERTERS—INVERTED

(SEE FIG. 6)

	Fractional loads	*A* Losses from input-output kw.	*B* Total losses from no-load readings kw.	*C* Load loss *A* — *B* kw.	*D* No-load core loss kw.	*E* Calculated armature I^2r loss kw.	$\frac{\lambda C + D + E}{D + E}$	Efficiency by separate losses	Efficiency by input-output
200 kw., 625-volt,	2/4	12.35	12.17	0.18	4.3	0.73	1.04	90.5	90.4
three-phase, 60 cycles	3/4	13.69	13.17	0.52	4.35	1.44	1.09	92.6	92.3
1200 rev. per min.	4/4	15.5	14.52	0.98	4.42	2.42	1.14	93.8	93.3
	5/4	17.88	16.16	1.72	4.48	3.61	1.21	94.3	93.7
(See Fig. 6)	6/4	20.45	18.00	2.45	4.57	5.05	1.26	94.7	94.0
200 kw., 575-volt	2/4	16.2	15.9	0.3	8.3	0.67	1.03	87.9	87.6
three-phase 60 cycles	3/4	17.64	17.0	0.64	8.5	1.30	1.07	90.7	90.3
1200 rev. per min.	4/4	20.0	18.21	1.79	8.6	2.16	1.17	92.3	91.7
	5/4	22.82	20.2	2.62	9.0	3.25	1.21	93.2	92.5
(See Fig. 6)	6/4	25.7	21.85	3.85	9.1	4.39	1.29	93.7	92.6

The results from a number of commercial tests of 60-cycle synchronous converters, are shown in Table VI. The efficiencies by input-output in all cases check very closely with those computed from the separate losses, using the correction factor 1.1 at full rated output, the value indicated by the laboratory tests.

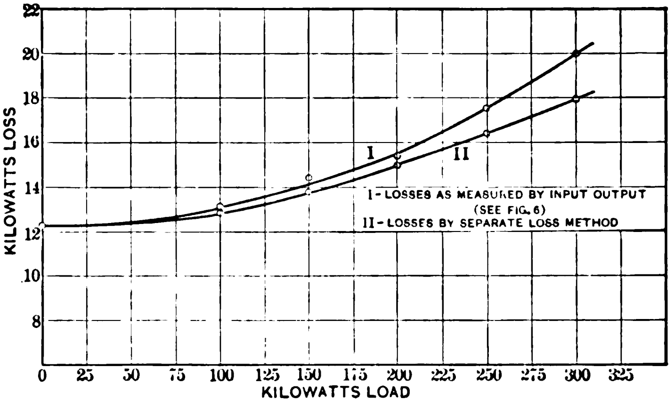

FIG. 7—SYNCHRONOUS CONVERTER, 200 KW., 625 VOLTS, 60 CYCLES, THREE-PHASE, 1200 REV. PER. MIN., NON-COMMUTATING POLE

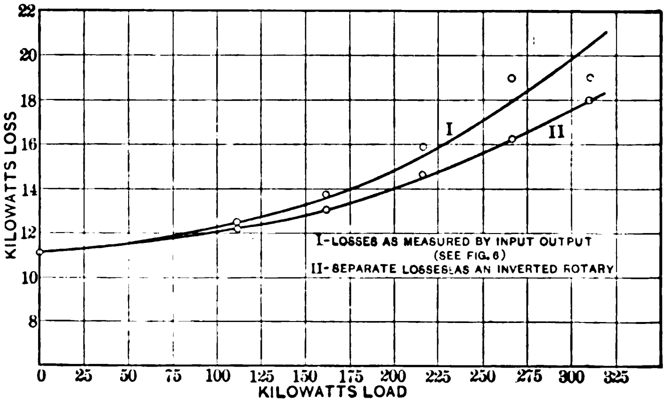

FIG. 8—SYNCHRONOUS CONVERTER INVERTED, 200 KW., 625 VOLTS, 60 CYCLES, THREE-PHASE, 1200 REV. PER. MIN., NON-CUMMUTATING POLE

No laboratory tests were made on 25-cycle synchronous converters or on commutating pole converters of either frequency. Results from a number of commercial tests shown in Table VII seems to indicate, however, that if there is any load loss on 25-cycle converters it is so small that it may be neglected.

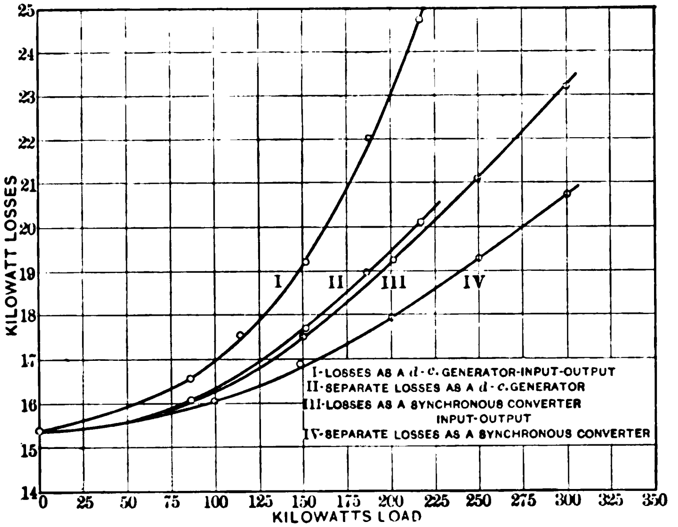

Fig. 9—Synchronous Converter, 200 kw., 575 Volts, 60 Cycles, Three-Phase, 1200 rev. per. min., Non-Commutating Pole

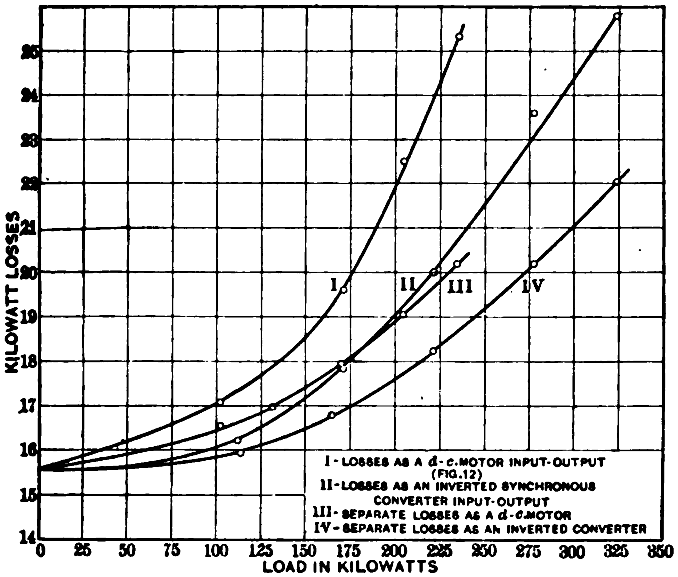

Fig. 10—Synchronous Converter Inverted, 200 kw., 575 Volts, 60 Cycles, Three-Phase, 1200 rev. per. min.. Non-Commutating Pole

TABLE VI

60-CYCLE SYNCHRONOUS CONVERTERS—COMMERCIAL TESTS—FULL LOAD READINGS

Machine	Core loss at no-load	Calculated armature I^2r	λ as determined by special test (See Fig. 6)	$\lambda(A + B)$	Kw. output	Total losses from no-load readings		Efficiency by separate losses		Efficiency by input output
						Without correction factor	With correction factor	Without correction factor	With correction factor	
200-kw., 275-volt, three-phase, 1200 rev. per min.	6.0	1.22	1.10	7.95	200.7	16.25	16.98	92.5	92.0	92.0
300-kw., 250-volt, three-phase, 514 rev. per min.	6.0	2.14	1.10	8.95	298.4	21.07	21.88	93.5	93.2	93.3
300-kw., 250-volt, two-phase, 900 rev. per. min.	7.30	1.47	1.10	9.65	299.9	20.56	21.44	93.4	93.3	93.1
500-kw., 250-volt, six-phase, 720 rev. per min.	5.95	4.16	1.10	11.12	504	25.92	26.93	95.0	94.7	94.6
1000-kw., 600-volt, six-phase, 600 rev. per min.	11.3	10.0	1.10	23.42	961	60.28	62.40	94.1	93.9	93.9
1000-kw., 600-volt, six-phase, 600 rev. per min.	10.1	8.21	1.10	20.15	1010	61.66	63.50	94.2	94.0	93.9

TABLE VII

25-CYCLE SYNCHRONOUS CONVERTERS—COMMERCIAL TESTS—FULL LOAD READINGS

	Core loss at no-load	Calculated armature I^2r loss	Total loss from no load readings	Kw. output	Efficiency by losses	Efficiency by input-output	Difference in efficiency
200-kw., 600-volt, three-phase, 750 rev. per min.	2.60	2.17	10.16	199.2	95.1	93.1	—2.0
300-kw., 600-volt, three-phase, 750 rev. per min.	2.4	4.92	13.0	293	95.7	96.4	+0.7
300-kw., 650-volt, three-phase, 750 rev. per min.	3.48	4.3	13.46	296.4	95.6	95.2	—0.4
300-kw., 650-volt, three-phase, 750 rev. per min.	3.95	4.59	14.78	319.7	95.6	94.8	—0.8
300-kw., 650-volt, three-phase, 750 rev. per min.	3.70	4.30	14.10	300.3	95.5	96.1	+0.6
300-kw., 650-volt, three-phase, 750 rev. per min.	4.20	4.21	15.11	299.3	95.2	93.5	—1.7
300-kw., 600-volt, three-phase, 750 rev. per min.	3.10	4.42	13.36	295	95.7	96.2	+0.5
500-kw., 600-volt, six-phase, 500 rev. per min.	10.6	2.04	21.43	523	96.1	95.6	—0.5
500-kw., 600-volt, six-phase, 500 rev. per min.	9.0	1.97	18.81	500.8	96.4	97.9	+1.5
500-kw., 600-volt, six-phase, 500 rev. per min.	13.4	2.06	25.37	525.2	95.4	96.5	+1.1
500-kw., 600-volt, six-phase, 500 rev. per min.	8.8	2.04	17.12	498	96.7	95.2	—1.5

TABLE VII—*Continued.*

	Core loss at no-load	Calculated armature I^2r loss	Total loss from no load readings	Kw. output	Efficiency by losses	Efficiency by input-output	Difference in efficiency
500-kw., 600-volt, six-phase, 500 rev. per min.	11.2	2.04	28.1	521.5	95.9	95.0	—0.9
500-kw., 600-volt, six-phase, 500 rev. per min.	8.8	2.04	25.8	538	95.4	94.3	—1.1
500-kw., 1200-volt, three-phase, 750 rev. per min.	5.76	8.1	23.32	499.5	95.5	95.3	—0.2
500-kw., 1200-volt, three-phase, 750 rev. per min.	4.05	8.88	19.81	501.4	96.2	97.0	+0.8
500-kw., 1200-volt, three-phase, 750 rev. per min.	4.90	8.65	22.11	500.6	95.8	96.6	+0.8
500-kw., 1200-volt, three-phase, 750 rev. per min.	4.50	8.95	21.24	499.6	95.9	96.7	+0.8
500-kw., 1200-volt, three-phase, 750 rev. per min.	4.98	8.82	22.76	500.4	95.7	96.5	+0.8
1000-kw., 650-volt, six-phase, 500 rev. per min.	11.50	5.57	36.72	1007	96.5	97.3	+0.8
2000-kw., 600-volt, six-phase, 375 rev. per min.	13.85	18.8	64.6	2008	96.9	98.0	+1.1

***Average difference in efficiency, 0.02.**

Readings were taken at different loads on a 25-cycle commutating pole machine during a temperature test while the meters were swinging somewhat due to variations in the power supply. The results from these readings are plotted in Fig. 11. This curve further indicated that load loss in the case of 25-cycle converters is a negligible quantity and that the efficiency calculated from the separate loss without correcting factors is sufficiently accurate for all commercial purposes.

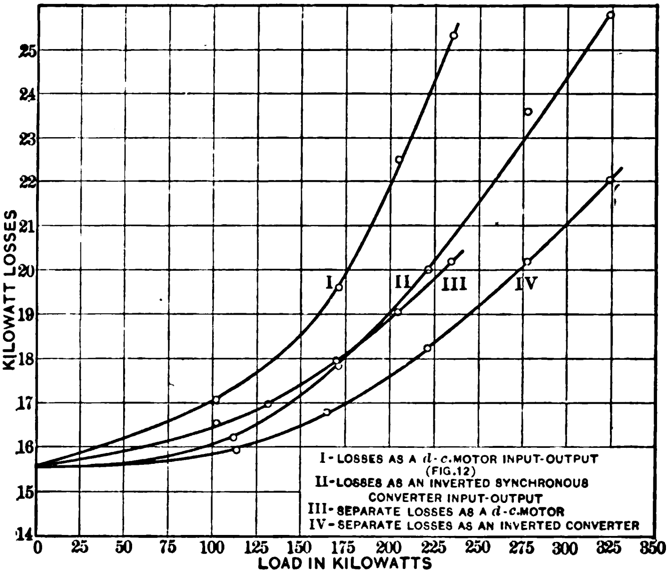

FIG. 11—SYNCHRONOUS CONVERTER, 500 KW., 600 VOLTS, SIX-PHASE, 25 CYCLES, 750 REV. PER. MIN., COMMUTATING POLE—COMMERCIAL TEST

SYNCHRONOUS CONVERTER AS D-C. GENERATOR

In addition to the straight input-output test as described above a second test was made on the same synchronous converters, operating them as direct-current machines. (See Fig. 12). The shafts of the two converters were coupled together mechanically and the pair of the machines was operated as a d-c. to d-c. motor-generator. A direct comparison of the performance of this type as a synchronous converter and as a d-c. generator was thus obtained. The results are shown on Figs. 9 and 10 and show very well the increase in load loss when operating as direct-current machines.

TABLE VIII. MOTOR-GENERATOR SETS—COMMERCIAL TESTS—FULL LOAD READINGS.

λ—for direct-current generator = 1.3 λ— for synchronous motor = 1.1

Machine	Synchronous motor						Direct-current generator						Set		
	A Core loss at no-load	*B* Calculated armature I^2r loss	$\lambda (A+B)$	Kw. input	Total losses from no-load reading		*C* Core loss at no-load	*D* Calculated armature I^2r loss	$\lambda (C+D)$	Kw. output	Total losses no-load readings		Over all efficiency by separate losses		Efficiency by input-output
					Correction factor						Correction factor		Correction factor		
					Without	With					Without	With	Without	With	
200-kw., 250-volt, commutating pole generator 290-h.p., 2200-volt, three-phase, 25-cycle Synchronous motor 750 rev. per min.	3.2	2.6	6.4	23.5	10.03	10.63	5.6	3.62	12	200	18.92	21.70	87.1	86.0	85.1
Three-piece set Two 250-kw., 650-volt, commutating pole d-c. generators 720-h.p., 13,200-volt three-phase, 60-cycle Synchronous motor 720 rev. per min.	15.5	7.9	25.78	570	31.4	33.6	5.6 5.5	4.88 4.95	13.61 13.59	248.5 248.5	20.13 20.10	23.27 23.24	87.4	86.1	87.3
400-kw., 250-volt, commutating pole d-c. generator 580-h.p., 220-volt, three-phase, 30-cycle Synchronous motor 600 rev. per min.	20.2	1.61	24	465.6	31.06	33.24	6.6	5.63	15.9	400	33.16	36.83	86.1	85.1	85.8

TABLE VIII—*Continued.*

Machine	Synchronous motor						Direct-current generator						Set		
	A Core loss at no-load	*B* Calculated armature I^2r loss	$\lambda\ (A+B)$	Kw. input	Total losses from no-load reading Correction factor		*C* Core loss at no-load	*D* Calculated armature I^2r loss	$\lambda\ (C+D)$	Kw. output	Total losses no-load readings Correction factor		Over all efficiency by separate losses Correction factor		Efficiency by input-output
					Without	With					Without	With	Without	With	
400-kw., 600-volt, commutating pole d-c. generator 580-h.p., 2200-volt three-phase, 60-cycle Synchronous motor 720 rev. per min.	9.0	4.2	14.52	453	21.3	22.6	4.0	6.06	13.08	400	23.86	26.88	89.8	88.9	88.3
1000-kw., 275-volt, commutating pole d-c. generator 1440-h.p., 5500-volt, two-phase, 60-cycle Synchronous motor 514 rev. per min.	36.0	8.6	49.1	1159	66.5	71	24.9	9.71	45	1000	74.51	84.9	87.7	86.6	86.3
1000-kw., 550-volt commutating pole d-c. generator 1440-h.p., 2200-volt, two-phase, 60-cycle Synchronous motor 514 rev. per min.	16.7	11.05	30.5	1124	46.26	48.96	11.60	13.35	32.4	1000	62.27	69.75	90.2	89.4	88.9

TABLE VIII—*Continued.*

	Synchronous motor						Direct-current generator						Set		
Machine	A Core loss at no-load	B Calculated armature I^2r loss	$\lambda\ (A+B)$	Kw. input	Total losses from no-load reading		C Core loss at no-load	D Calculated armature I^2r loss	$\lambda\ (C+D)$	Kw. output	Total losses no-load readings		Over all efficiency by separate losses		Efficiency by input-output
					Correction factor Without	With					Correction factor Without	With	Correction factor Without	With	
1000-kw., 600-volt, commutating pole d-c. generator 1440-h.p., 4600-volt, two-phase, 60-cycle Synchronous motor 514 rev. per min.	18.0	7.85	28.45	1143	50.11	52.7	32.2	11.3	56.5	1000	82.47	95.51	88.3	87.2	87.5
125 PER CENT LOAD READINGS λ—direct-current generator = 1.4 λ—synchronous motors = 1.2															
400-kw., 600-volt, commutating pole d-c. generator 580-h.p., 2200-volt, three-phase, 60-cycle Synchronous motor 720 rev. per min.	8.9	6.1	18	561	25.25	28.25	4.1	8.8	18.07	500	27.45	32.6	90.5	89.2	89.1
240-kw., 500-volt, commutating pole d-c. generator 370-h.p., 370-volt, three-phase, 60-cycle 1200 rev. per min.	5.2	4.3	11.4	342	14.8	16.7	4.6	7.05	16.3	300	22.8	27.5	88.9	87.1	87.8
150-kw., 250-volt, commutating pole d-c. generator 225-h.p., 440-volt, three-phase, 60-cycle 900 rev. per min.	8.3	2.8	13.32	226.5	15.0	17.22	6.2	4.4	14.86	187.5	19.1	23.35	84.6	82.2	82.7

MOTOR-GENERATOR SETS

A number of motor generator sets were examined and the constants determined from the laboratory tests were applied to the sum of the no-load core losses and calculated armature copper losses of each machine. The overall-efficiency of the set from the corrected losses was then calculated and compared with the over-all efficiency from the input-output readings taken during commercial tests. The results are shown in Table VIII.

While an examination of these results shows some discrepancies, it must be remembered that the input-output tests are merely of the commercial variety and are probably as nearly correct as average tests of that description.

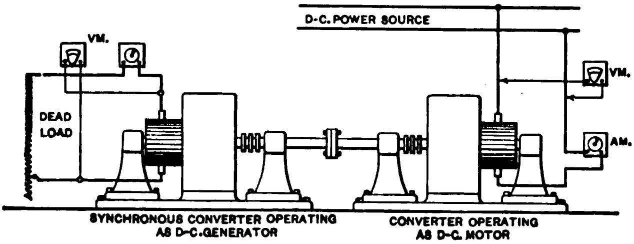
D-C. POWER SOURCE
VM.
VM.
AM.
DEAD LOAD
SYNCHRONOUS CONVERTER OPERATING AS D-C. GENERATOR
CONVERTER OPERATING AS D-C. MOTOR

FIG. 12—INPUT-OUTPUT TEST OF SYNCHRONOUS CONVERTERS AS DIRECT-CURRENT MACHINES

RECOMMENDATIONS

As a result of our investigation we suggest the use of correction factors for computing from the separate losses, the efficiencies of the rotating electric machines discussed in this paper, namely—a-c. generators, synchronous motors, d-c. generators, d-c. motors, and synchronous converters. The said correction factors to be applied to the sum of the no-load core loss and the armature I^2r loss, as calculated from no-load measurements of resistance. We submit the following values as being approximately correct for well-designed apparatus of the types mentioned:

Fractional loads		Value of constant			
		2/4	3/4	4/4	5/4
Direct-current generator					
Direct-current motor		1-1	1-2	1-3	1-4
Alternating-current generator	*Stranded conductors	1-01	1-03	1-10	1-2
Synchronous motor					
†60-cycle synchronous converter		1-04	1-07	1-10	1-2
All 25 cycle synchronous converters		1	1	1	1

* Does not apply to machines with deep strap conductors, in which the eddy current loss in the copper may be large.

† Non-commutating pole type. Tests on commutating-pole type not completed.

These values apply only to well designed machines, as shown by moderate losses, low temperatures and satisfactory behavior at the commutator.

In the case of machines having undue temperature elevations or those showing faulty commutation, the load losses may be of considerable magnitude and the above constants will not hold good. Such machines should be investigated individually according to the method described herein if the true efficiency is to be determined.

NOTES ON STRAY LOSSES IN SYNCHRONOUS MACHINES

BY

F. K. BRAINARD

Presented under the auspices of the

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NOTES ON STRAY LOSSES IN SYNCHRONOUS MACHINES

BY F. K. BRAINARD

ABSTRACT OF PAPER

The present Standardization Rules recommend that one-third of the "short-circuit core loss" be taken as stray loss for the computation of efficiency of synchronous machines. An analysis of short-circuit tests of quite a variety of machines indicates that this is too small an amount and it is recommended that the Standardization Rules be revised to include a greater part of the "short-circuit core loss" as stray loss.

The tests show that in the case of slow or moderate-speed machines practically all of the short-circuit loss can be accounted for by armature resistance loss plus eddy current loss, and that there is very little short-circuit loss in the armature core in case it is well built. In the case of high-speed turbo-generators there is a large loss appearing on short circuit which cannot be accounted for by eddy currents in the conductors. A large portion of this is due to eddy current and hysteresis loss in the unlaminated parts of the machine. An additional reason for taking more of the "short-circuit core loss" as stray loss in the case of a turbo-generator is that there is probably an appreciable additional loss with actual load on account of increased magnetic leakage from the field resulting from the increased excitation required.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26-28, 1913.

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(*Subject to final revision for the Transactions.*)

NOTES ON STRAY LOSSES IN SYNCHRONOUS MACHINES

BY F. K. BRAINARD

Since the Institute rule of taking "load loss," which may more properly be called stray loss, seems in error, an analysis of short-circuit tests of synchronous machines was made with the idea of determining, if possible, the nature of this loss and so the probable relationship between stray loss with actual load on the machine, and the measured loss on short-circuit which cannot be accounted for by armature I^2R.

These losses are probably due almost entirely to the following causes:

a. Eddy current loss in the armature conductors, or rather extra loss due to the unequal distribution of current in the conductor. See *Eddy Currents in Large Slot Wound Conductors,* A. B. Field, TRANSACTIONS A. I. E. E., 1905, XXIV p. 761.

b. Eddy current and hysteresis loss due to flux from the armature coils getting into parts of the machine not intended to carry magnetic flux, such as coil supports, end shields, etc.

c. Extra eddy current and hysteresis loss due to the change in distribution of flux in the magnetic circuit.

The eddy current factor for each machine was computed according to Field and the tests were plotted upon logarithmic paper to determine the law of variation of short-circuit loss with armature current.

In the case of slow or moderate-speed machines it was found that the loss varied practically as the square of the armature current and that the stray loss unaccounted for by cause (a) mentioned above was small and usually negligible. The loss due to cause (b) will be small in this case on account of the relatively short ends of the coils. Hence it would appear that the stray loss due to cause (c) in slow-speed machines is negligible or can practically be eliminated by proper construction of armature cores.

In the case of high-speed turbo-alternators the loss unaccounted for by eddy currents in the conductors is large, and short-circuit tests made with and without end shields indicate that cause (b) previously mentioned is mainly responsible. In one case removal of the end shields reduced the loss on short-circuit 28 per cent. Hence it would seem that even in this case there is very little stray loss in the core of a well built machine.

For any synchronous machine the loss due to the "Field effect" is probably practically the same on load as on short-circuit for the same armature current. The same undoubtedly applies to the loss due to flux from the armature coils getting into the unlaminated parts of the machine. However, the loss due to change in distribution of the magnetic flux is probably considerably greater on short-circuit than with the same armature current at full voltage; but since this part of the stray loss can probably be reduced to a negligible amount by proper design and workmanship, it would seem that the Institute rule should be modified to make stray loss equal to, say, one half of the difference between the measured short-circuit loss and the calculated I^2R loss, instead of one third of this difference as at present.

Then the total losses in any synchronous machine would be determined as follows:

1. Core loss windage and friction, determined by driving the machine with a separate motor at normal speed and normal voltage with the armature open-circuited. This to be assumed constant at all loads.

2. Armature resistance loss and stray loss, determined by driving the machine at normal speed with the armature short-circuited and with sufficient excitation to cause full-load armature current to flow. Of course the power required to drive the machine unexcited should be deducted so as not to include windage and friction twice.

3. Field excitation loss to be calculated from the field resistance hot, the amperes excitation being determined from the regulation curves.

It has been suggested that in the case of turbo-alternators there is an additional loss under load which does not appear on either open-circuit or short-circuit, due to the increased leakage flux from the field resulting from the greater exciting current. However, no attempt has been made, to the writer's knowledge, to measure this loss, but the probable existence of it should serve as an additional argument for taking more than one third of the "short-circuit core loss" as stray loss.

The following table gives the results of a number of short-circuit tests on various machines. The column headed "*n*" is the exponent in the equation kw. $= aI^n$ obtained by plotting upon logarithmic paper, where kw. = total loss on short circuit I = armature current and a and n are constants.

Rating of generator					Calculated armature copper* loss at full load	Measured short-circuit loss with full load current	*n*	Short circuit loss	Eddy current constant
Kv-a.	Volts	Phase	Cycle	Rev. per min.				Calc. I^2R	
2100	2300	3	25	107	22.4	25.7	2.16	1.15	1.29
1000	2300	3	25	94	17	19	1.86	1.12	1.12
250	1100	2	60	120	5.8	5.7	2.15	0.98	1.00
250	480	3	60	120	8.2	8.2	1.95	1	1.03
375	600	3	60	120	9.9	10.5	2.07	1.06	1.00
600	240	3	25	125	8.1	11.7	2	1.44	1.30
600	2300	3	60	150	7.6	9.2	2.07	1.21	1.19
300	4150	3	60	600	3.1	4.2	1.61	1.35	1.00
300	4150	3	60	600	3.1	3.1	1.95	1	1.00
400	7500	3	30	150	9.9	9.5	1.99	0.96	1.00

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* The calculated copper loss is based upon 50 deg. cent. coil temperature. As the temperature of the stator coils was not read during the short-circuit tests, a part of the lack of agreement between the calculated and measured short-circuit loss is undoubtedly due to this.

EFFECT OF AIR TEMPERATURE, BAROMETRIC PRESSURE AND HUMIDITY ON THE TEMPERATURE RISE OF ELECTRIC APPARATUS

BY

C. E. SKINNER, L. W. CHUBB and PHILLIPS THOMAS

Presented under the auspices of the

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EFFECT OF AIR TEMPERATURE, BAROMETRIC PRESSURE AND HUMIDITY ON THE TEMPERATURE RISE OF ELECTRIC APPARATUS

BY C. E. SKINNER, L. W. CHUBB AND PHILLIPS THOMAS

ABSTRACT OF PAPER

The paper discusses heat dissipation, and after citing the present Standardization Rules of the Institute in regard to " Temperature Corrections " points out that it is not only the copper resistance changes, therein assumed, which affect temperature rise, but also variations in other internal losses and heat dissipation.

Then follows a discussion of the effect on temperature rise of barometric pressure, humidity and changes in resistance loss, iron loss, radiation, viscosity and thermal constants of the cooling medium, friction windage and condition of operation.

It has been noted that in many cases the rise at high temperature is lower instead of higher as assumed in the Standardization Rules, and the authors made tests to determine some of the fundamentals which govern the emission of heat and temperature rise at different air temperatures.

The tests made and data given cover only the direct effects of air temperature air pressure and humidity.

The apparatus and methods of test are described and the results for variations in temperature and air pressure are shown graphically.

The tests show that within commercial limits and at constant input the temperature rise is independent of air temperature, provided the walls or objects to which heat may be radiated are at the same temperature as the air.

Barometric changes are shown to affect the temperature rise somewhat and the statement is made that humidity has no appreciable effect upon the result.

The conclusion drawn is that instead of the correction specified by the Standardization Rules, no correction should be made for variation of air temperatures within the usual testing limits. This conclusion is based on the facts that there are a number of variations, some of which are positive, some negative and some either positive or negative depending on operating conditions.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26–28, 1913.

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(*Subject to final revision for the Transactions.*)

EFFECT OF AIR TEMPERATURE, BAROMETRIC PRESSURE AND HUMIDITY ON THE TEMPERATURE RISE OF ELECTRIC APPARATUS

BY C. E. SKINNER, L. W. CHUBB AND PHILLIPS THOMAS

Heat is dissipated from any given piece of electrical apparatus through conduction, convection and radiation. The proportion dissipated through conduction and radiation is usually quite small, although heat is readily conducted from one part of a machine or apparatus to other parts and to supports in contact. The heat dissipated by convection, as a rule, takes care of the major part of the loss.

The present Standardization Rules of the Institute, under the heading of " Temperature Correction " (Section 269), read as follows: " If the room temperature during the test differs from 25 deg. cent., correction on account of difference in resistance should be made by changing the observed rise of temperature by one-half per cent for each degree centigrade." This correction is required, apparently, on the assumption that the increase in resistance of the copper windings is the controlling feature causing such variation.

The factors which affect the variation in temperature rise in a piece of electrical apparatus include the following:

First: Variation in resistance with temperature. The resistance of the copper increases with temperature and the correction for copper loss should be plus or minus, depending on whether the current in a given winding is constant or whether the voltage across the winding is constant.

Second: Variation in iron loss with temperature. Other conditions being constant, iron loss decreases as temperature increases, due

a. To increased resistance reducing eddy current losses.

b. Decreasing hysteresis losses.

Third: Variation in amount of heat radiated at different temperatures. Under ordinary conditions the amount of heat radiated will vary with the increase in difference between the temperature of the body from which heat is radiated and the temperature of the surrounding objects. The effect of radiation on temperature rise will depend on surrounding conditions, but as a rule there will be more heat radiated from higher temperatures than from lower temperatures.

Fourth: Variation in convention due to variation of viscosity of the cooling medium. There is probably not sufficient variation in the viscosity of air to warrant any correction whatever for viscosity in air-cooled apparatus. This feature becomes quite a factor in oil-cooled apparatus where the fluidity of the cooling medium increases with temperature, and consequently, its ability to carry away heat by increased rapidity of circulation.

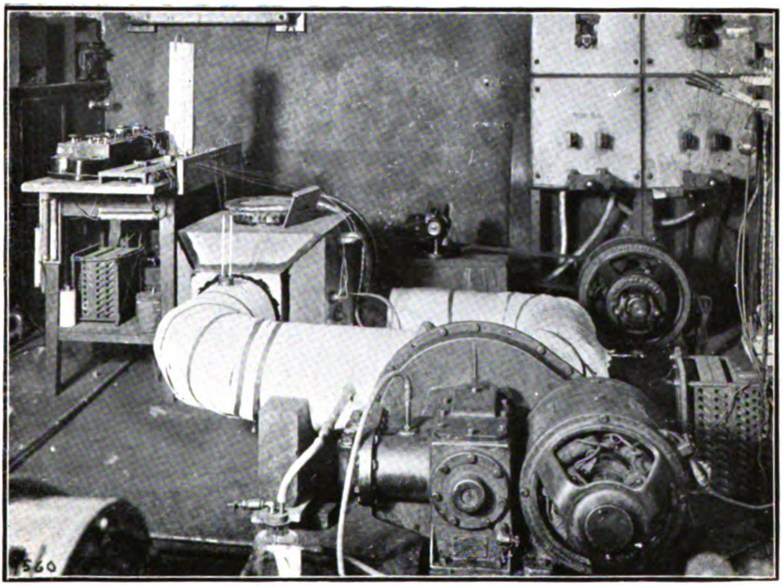
Fifth: Variation due to change in thermal conductivity of the air at different temperatures.

Sixth: Variation due to barometric pressure. It is to be expected that with decreased barometric pressure there will be increased temperature rise, and the results of a given set of tests under specific conditions, recorded later, indicate an increasing rise with decreased pressure.

Seventh: Variation due to humidity. It has been assumed that on account of the heat carrying power of water vapor there should be a decreased rise due to increased humidity. This corrective factor is, however, probably very small.

Eighth: Variation in bearing friction, brush friction and windage.

Ninth: Variation depending on whether the apparatus is acting as a motor or generator at constant voltage, or whether it is operating at constant load, constant current or constant loss. Whether the total losses on a given piece of apparatus increase or decrease with temperature, depends on how the apparatus is operated and on the relation of the various segregated losses to each other. If operating as a generator with constant output the copper losses will increase with rise in air temperature and the iron losses may increase or decrease. If the iron loss pre-



[SKINNER, CHUBB AND THOMAS]

SHOWING APPARATUS USED IN MAKING TESTS.

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dominates the result may be a decrease in actual losses with increase in air temperature, giving a lower rise. If operating as a motor or transformer and connected to a constant voltage, increased air temperature may again either increase or decrease the total losses, and the rise, as in the case of a generator.

A number of tests indicating that the correction for temperature rise when the air temperature is higher than 25 deg. cent. should be negative instead of positive, as required by the Standardization Rules, has led to a set of tests being made to determine some of the fundamentals which govern temperature rise from different temperatures. It will readily be seen from the foregoing that the problem is an extremely complicated one and that it is necessary, therefore, to fix certain conditions and provide for the observing of one variable at a time, keeping the others constant if possible. The factors which were controlled in these tests were:

a. Radiation
b. Air temperature.
c. Barometric pressure.
d. Humidity.
e. Wind velocity.
f. Input.

All tests were made with a constant input to the test coil.

The apparatus selected for test was a small motor field coil, of about 9 ohms resistance at 20 deg. cent. The coil was about 6.35 cm. (2.5 in.) by 1.9 cm. (0.75 in.) in section, and was wound on a center block about 9 cm. (3.5 in.) by 5 cm. (2 in.) This coil was hung in the center of a closed cubical box, about 61 cm. (2 ft.) on a side. At two opposite ends of the box, connection was made with an air circulating pipe 30.5 cm. (1 ft.) in diameter, which formed a closed system with the box and a blower. The whole system was made as nearly air-tight as possible, and variation in internal pressure was secured by means of a motor-driven air pump used either to exhaust or compress the air in the system. A cubical sheet metal baffle was mounted inside the coil box, equipped with a fine mesh screen at the ends through which the air entered and left the coil space. About two inches (51 mm.) of free air space was left on all sides between the baffle and the coil box, in order to be sure that the temperature of the baffle wall and the air surrounding the coil should be the same. The screen across the ends of the baffle also extended across the clearance to the inside of the coil box. The pressure within the system was read on a differential mercury manometer communicating with the atmosphere outside; the external pressure was given by a carefully adjusted aneroid barometer. The velocity of the circulating air was measured by the cooling effect upon a small copper wire suspended directly beneath the coil, the air speed being calculated from the current necessary to maintain the resistance of this wire, between definite potential points, at a predetermined constant value.* The temperature of the coil, and of the air directly above and below the coil, was given by iron-advance thermocouples. The coil couple was mounted in contact with the covering of the wire on the extreme upper surface of the coil, which was subsequently given a serving of cotton tape and two coats of black armature varnish and baked dry. The relative humidity of the circulating air was determined from the readings of a wet and dry bulb thermometer, with the bulbs in the path of the air just before entering the coil enclosure. The temperature of the circulating air could be varied within wide limits by electric heater elements inserted in the air-pipe just after leaving the coil box, so that the heated and cooler air would be thoroughly mixed before again entering the enclosure. Fig. 1, schematic, shows the location of the coil, velocity wire and thermocouples, the leads from all of which were brought out through rubber corks in the sheet iron covering of the coil box.

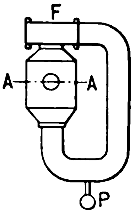

FIG. 1A—TOP VIEW OF APPARATUS

F — Blower.
P — Air pump.

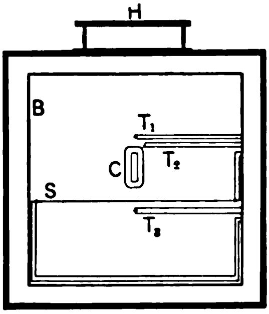

FIG. 1B—SECTION A-A, SCHEMATIC

C — Coil tested.
S — Speed wire.
T_1, T_2, T_3 — Thermocouples.
B — Air baffle.
H — Handhole for making adjustments.
Direction of flow of air is at right angles to plane of section.

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*Kennelly, Wright and Van Bylevelt, TRANSACTIONS A. I. E. E., 1909, XXVIII, I, p. 363.

The temperature elevation of an air-cooled coil is apparently influenced by so large a number of factors, that the futility of an attempt to determine the effect of each of them, in the time available, was apparent at the outset. The most important of the controlling factors are the temperature and pressure of the surrounding air. The major part of the work was then concentrated upon determinations of the effects of these two factors. Two sets of runs were made: First, with constant watts input in the tested coil, and constant pressure and speed of the circulating air, the temperature in the enclosure was varied by small steps from 30 to 64 deg. cent., and the temperature of the coil was taken at each point. Second, with constant watts input in the tested coil, constant temperature in the enclosure, and constant speed of air circulation, the air pressure in the enclosure was varied from 82.8 cm. (32.6 in.) to 53.4 cm. (21.2 in.) of mercury, in small steps, and the temperature rise of the coil was taken at each point. No readings were finally recorded at any point, until the instrument readings had all been constant for at least half an hour.

The current passed through the test coil was measured by a precision ammeter, and the difference of potential between the terminals of the coil was measured by a precision voltmeter connected to potential leads. Rough tests indicated that the temperature elevation of the coil was about 28 deg. cent. when carrying 32 watts, and the coil current and potential difference were kept such as to maintain this input as nearly constant as possible during the tests. The current through the speed wire was adjusted to give the same temperature elevation as in some previous work which has been presented before the Institute; this current was measured by a low-scale ammeter, and the potential across a length of the wire equal to that used in the same tests, was measured by a potentiometer.

Readings of the wet and dry bulb thermometers were made at each point in every test, with the intention of correcting for the slight variations in humidity unavoidably occurring; but a subsequent test, made with the air nearly saturated by blowing steam into the system, showed no significant change in temperature rise, and it was thought inadvisable to attempt any such corrections.

RESULTS

A. Tests at Constant Air Pressure and Speed. Fig. 2 shows in graphic form the results of these tests. Each point required several hours for its determination, so that the test as here recorded extended over several days. The curve between box temperature and coil temperature, plotted to the same scale, is plainly a straight line, within errors of observation and of adjustment of the controlling factors: the points as obtained do not indicate any regular deviation from a straight line. The intercept value of temperature rise as given by this line, agrees closely with the average of the point values, which means that the temperature elevation is constant. It may be mentioned here that the readings on the speed wire, worked out by the equation given for the same size, length and temperature of wire, in the paper already mentioned, gave an air velocity of 146 cm. per sec. (3.27 miles per hour) for a blower speed of 789 rev. per min. This speed was read on a tachometer and was kept very closely constant during the entire test. The temperatures above and below the test coil proved to be identical, when the air was circulated at this speed. Table I gives the observational results from which the curve of Fig. 2 was plotted.

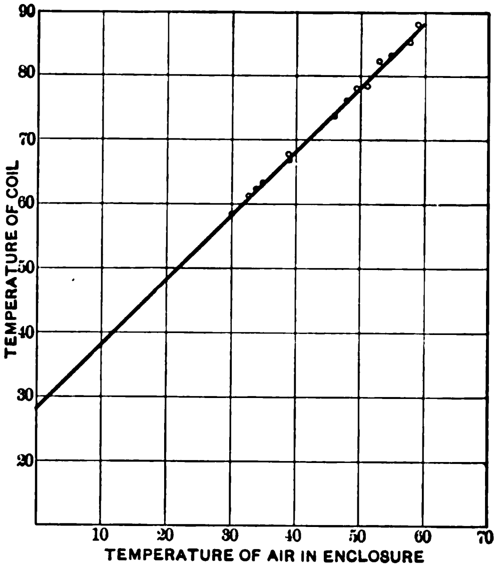

FIG. 2—VARIATION OF TEMPERATURE RISE OF COIL WITH CHANGING TEMPERATURE OF SURROUNDING AIR

B. Tests at Constant Air Temperature and Speed. The results of these tests are shown in Table II, and graphically in Fig. 3. The column headed "coil input" shows the variations that occurred in this quantity during the test. In order to correct the temperature rise for this error, a test was subsequently run between watts input and temperature rise, at the same fan speed and box temperature as were employed in the present test, and at constant air pressure. The results showed the relation between coil temperature and coil input to be very nearly linear—the exact equation found was

$$W = K\theta^{1.015}$$

Accordingly a correction was made at each point taken; the curve plotted in Fig. 3 is taken from these corrected values. As this curve shows about a 13 per cent variation in temperature rise for a decrease of 15 cm. (5.9 in.) in atmospheric pressure, which corresponds to a change in altitude from sea level to 1.9 km. (6240 ft.) above sea level, the importance of determinations of the magnitude of this effect on finished electrical apparatus is at once apparent. It is possible that some of this increase in temperature rise, as the air pressure is decreased, may be due to changes in the air velocity at different pressures with the same seed; but operating conditions are much more nearly those of constant fan speed than of necessarily constant air velocity.

TABLE I

EFFECT OF VARIATION OF TEMPERATURE OF ENCLOSURE UPON TEMPERATURE RISE OF COIL

Couple temperatures deg. cent			Coil input, watts	Blower speed rev. per min.
Air in box	Coil	Coil rise		
64	92	28	31.6	787
62.5	90.2	27.7	31.7	789
59.6	88	28.4	31.9	787
58	85.2	27.2	31.7	760
55	83	28	31.7	790
53.2	82.2	29	31.6	789
51	78.5	27.5	32.6	785
49.5	78	28.5	31.2	790
48.5	76.2	27.7	31.9	790
46.1	73.5	27.4	31.9	782
39.2	67	27.8	31.5	776
39.2	66.8	27.6	31.6	781
39	67.5	28.5	31.9	780
35	63.1	28.1	31.8	777
34	62.2	28.2	31.7	783
33	61	28	32	787
30	58.2	28.2	31.7	779

SUMMARY

The tests which have been completed at the time of the writing of this paper are:

First: The determination of the rise in temperature, all features being kept constant, except the temperature of the air and the surrounding walls.

Second: The determination of the variation in rise of temperature, all features being kept constant, except the barometric pressure.

Third: Some additional data were obtained showing variation of rise in temperature, all features being kept constant, except humidity of the surrounding air, but no difference in temperature rise due to variation in humidity was found.

Tests are under way to determine the rise in temperature, keeping all features constant, except the temperature of the surrounding air, with a view to determining the effect of varying radiation.

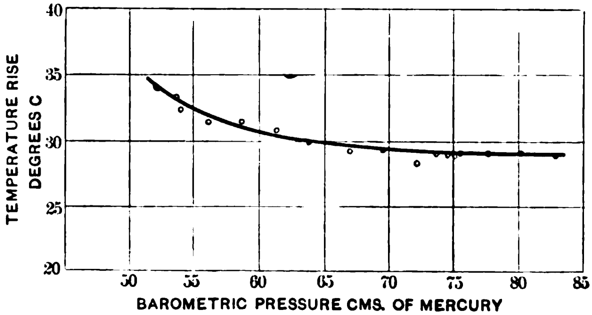

FIG. 3—VARIATION OF TEMPERATURE RISE OF COIL WITH BAROMETRIC PRESSURE

Results of the first set of tests are shown in Fig. 2. It will be seen that within the limits of error of observation and under the conditions of the test as made, a variation in the temperature of the air surrounding the coil does not affect the temperature rise. The slight difference in the amount of heat radiated from the coil at different temperatures, even though the surrounding walls were kept at air temperature, does not appear in the recorded results and must, therefore, be very small.

Results of the second series of tests are shown in Fig. 3 and indicate that there is a sufficient amount of variation in the temperature rise of electrical apparatus between sea level and an altitude of five thousand feet, for example, to require a relatively small corrective factor. The data obtained are, however, probably not sufficiently conclusive to warrant making provision at this time for such correction.

The tests so far recorded with variation in humidity have shown no appreciable variation in temperature rise and these results agree with other work which has been done along this line.

A theoretical discussion of the variation in temperature rise due to variation in radiation, would indicate that under certain conditions the temperature rise from higher air temperatures might be less than from lower air temperatures. As the general tendency of the other factors which affect temperature rise from different air temperatures is to oppose the effect of radiation, these corrections will in general tend to cancel each other.

TABLE II

EFFECT OF PRESSURE VARIATION UPON TEMPERATURE RISE OF COIL

Air pressure		Couple temperatures deg. cent.			Coil input, watts	Blower speed rev. per min.	Corrected coil rise
Cm.	In.	Air in box	Coil	Coil rise			
82.7	32.6	41	69.5	28.5	31.7	785	28.7
80.2	31.6	40.8	69.6	28.8	31.7	786	29
77.6	30.5	40.9	69.7	28.8	31.8	784	29
75.5	29.7	41.8	70.5	28.7	31.8	789	28.9
75.3	29.6	40.9	69.5	28.6	31.8	785	28.8
74.6	29.2	40.2	68.9	28.7	31.8	784	28.9
73.7	29	40	67.8	27.8	31.6	782	29.1
72.3	28.5	40.2	69.0	28.8	31.6	787	28.2
69.6	27.4	40	68.8	28.8	31.7	790	29.1
66.9	26.4	40.7	69.5	28.8	31.7	788	29.1
63.8	25.1	40.7	70.3	29.6	31.7	784	29.9
61.4	24.2	40.5	71.2	30.7	32	786	30.7
58.7	23.1	40.5	73.5	33	33.7	785	31.4
56.2	22.1	40.2	73.1	32.9	33.6	787	31.4
54.1	21.3	40.2	72.5	32.3	31.6	787	32.4
53.8	21.2	40.4	73.5	33.1	31.8	788	33.4

CONCLUSION

It will be seen from the foregoing discussion that the problem of the variation in temperature rise from different air temperatures is quite complex and that in some cases the same item of loss may tend to increase or decrease the temperature rise, depending on the conditions under which the apparatus is operated. The conclusion which can be drawn from the tests made, is that while there are a number of things which would make the temperature rise from one air temperature differ from that of another, these tend to cancel each other and, therefore, the omission of any corrective factor for variation in air temperature would be more nearly in accordance with the facts than the provision made in the existing Standardization Rules.

CURRENT RATING OF ELECTRIC CABLES

BY

RALPH W. ATKINSON and H. W. FISHER

Presented under the auspices of the

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CURRENT RATING OF ELECTRIC CABLES

BY RALPH W. ATKINSON AND H. W. FISHER

ABSTRACT OF PAPER

This paper is a discussion of the current carying capacity of electric power cables. The limiting temperatures are discussed. The relation of the temperature rise of cables suspended in free air to the rise under other conditions is considered, the rise in free air being treated specifically, formulas being given for the calculation of this rise. The rise of temperature with loads of brief duration is discussed. Tables are given showing permissible overload ratings, these tables being applicable under all ordinary conditions.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26-28, 1913.

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CURRENT RATING OF ELECTRIC CABLES

BY RALPH W. ATKINSON AND H. W. FISHER

At the request of the Standards Committee this paper has been prepared, the object being to present data relative to the carrying capacity of cables, which will be of value to engineers and users of cables. Especial attention is called to Table I (to be explained later) which gives data relative to the overload capacity of cables which have been working at different percentages of the normal carrying capacity. This question comes up frequently, engineers asking what per cent of overload can be applied to different cables. The per cent of such overload must of course depend upon the per cent of normal load at which the cable has been operating for several hours previous to the application of the overload. It is hoped that the formulas presented will be of value to engineers who have to deal with the subject under consideration.

The current rating of an electric cable depends entirely upon allowable heating, and is often more dependent upon or limited by external conditions than upon conditions intrinsic in the cable itself. On account of the extreme variability of these external conditions, the current rating of any given cable may be reduced to a half or a third, or even a small fraction of its normal rating. The time during which a cable may carry any given per cent overload is shorter than the time during which most other electrical apparatus can carry the same per cent overload. The allowable overload for any given duration of time depends simply upon the rate at which the cable will be heated to its limiting temperature. This is much more dependent upon the properties of the cable itself, than is the ultimate carrying capacity.

Very many formulas have been given as representing the carrying capacity of cables, beginning with the old rules which allow a certain number of circular mils per ampere. There is only one simple formula connecting the carrying capacity of conductors of different cross-sectional area which we have found useful and accurate. For nearly all conditions, it may be stated that the carrying capacity varies as the 1.3 power of the diameter of the equivalent solid conductor.

We will first discuss the limiting temperature. When insulating material is maintained at an excessive temperature, the first noticeable permanent change is in brittleness. It is sometimes important that this is true and that the first change is not in dielectric strength or, in fact, in tensile strength. A cable will sometimes work satisfactorily long after the insulation is badly injured by overheating, but only as long as it is undisturbed. The insulation of most non-rubber-insulated cables will stand a temperature of 150 deg. cent. for a very brief time without apparent permanent injury. If this temperature is maintained for more than a very short time, a matter of minutes, permanent injury results.

The limiting temperature is very much lower than this when it is maintained for a long period. To insure that progressive deterioration does not take place, the maximum temperature has been set by some as 65 deg. cent. and by others at 75 deg. For rubber, the temperature limit is lower and has been set at 50 deg. cent. For high-voltage cables, 6000 volts working pressure and above, another factor must be considered. The dielectric loss increases rapidly at the higher working temperatures, thus causing material additional heating. By some it has been said that the dielectric strength is much less at high temperatures, but we believe that this opinion was conceived because of the greater dielectric loss at high temperatures. A temperature limit of 50 deg. cent. has been named as the limit for high-voltage fibrous insulated cables. We believe that a temperature of 65 deg. cent. will not injure paper-insulated cables but the increasing dielectric loss with increasing temperature must be considered and no exact rule can be given, as some insulating materials have a very considerably lower dielectric loss at high temperatures than others. We most earnestly hope to hear a thorough discussion of this question.

The temperature rise of a cable may be considered to be made up of:

1. The rise of copper above lead.
2. The rise of lead above immediate surroundings.
3. The rise of temperature of the surroundings due to the presence of the cables in the neighborhood.

It is only by an analysis of these elements that a general knowledge of temperature rise under all conditions can be obtained without experiment under any specific conditions for which information is desired. We intend to devote our attention to the first two elements of temperature rise in the present paper, these being the ones which are most nearly independent of variable external conditions. (For data concerning the other conditions we would refer to a paper read before the British Institution by Nelsom and Booth in 1911. This paper also containedr eference to a number of others. We would refer also to pages 213, 214 and 215 of Foster's "Electrical Engineer's Handbook," these data being based upon former experiments by one of the authors). We will take up individually the two elements to be considered.

The rise of copper above lead is equal to

$$t_1 = n\, b \log D/d \;\frac{I^2 \times 1000}{C.\,M.}$$

Where D/d is the ratio of the inside diameter of the lead sleeve to the outisde diameter of the copper conductor.

I is the current flowing in the conductor.

$C.\ M.$ is the cross-sectional area of the cable in circular mils.

b is an empirical "constant" which depends upon the kind of insulation and somewhat upon the temperature. For practical purposes, it may be taken, for either paper insulated or varnished cloth insulated cables, as 0.27. (See below for value for triplex cable.)

n is the number of conductors.

This formula may be applied directly to the case of concentric cables simply by adding the temperature rise from copper to copper and from copper to lead, remembering that the heat from two or from three conductors must pass through the outer layer of insulation.

For flat duplex cables, the temperature rise may be taken as about 15 per cent greater than that of a single conductor cable with the same thickness of insulation. For triplex or round duplex cables we can use this formula if we use, for d, the diameter of the circle circumscribing the three conductors. We must also use a different value of "constant." By experiment, this has been found to be from 0.285 to 0.33, the latter value being for cables where the insulation is very thin relative to the size of the conductor.

The rise of lead above air or surrounding objects is

$$t_2 = n\,a\,\frac{I^2 \times 1000}{d_1\,C.\,M.}$$

Where d_1 is the outside diameter of the lead sheath in inches a may be taken as 0.11. This value applies where a clean bright lead sheath is suspended in free air. The value of a changes considerably with the size of the sheath, being less when the diameter is small. Preventing the natural circulation of air, increases a, while even a slight forced circulation decreases it materially. A rough, black coating on the lead will also reduce the value of a. For a flat duplex cable, use the formula as for a single conductor and increase the temperature rise of cable about 20 per cent.

It is very interesting that the temperature rise of a cable is very nearly the same regardless of the thickness of insulation. This is because the change of the rise of lead above air counterbalances the change in the rise of copper above lead when the thickness of insulation is changed. Moreover, the experiments upon the rise in temperature of cables in air, of which these formulas are an expression, show practically the same temperature rise for a cable suspended freely in air as previous experiments show for a cable of the same kind laid in a duct system, no other cables being present. The table on page 215 in the previously mentioned section of Foster's Handbook may be used directly to give the carrying capacity of a three-conductor cable in free air when the permissible temperature rise is 45 deg. cent. The values should be increased one-third for single-conductor cables. Thus we see that not always do wide variations materially affect the carrying capacity of cables.

The temperature rise of a bare conductor in free air follows a very simple and easily derived law very closely. We may neglect the variation of a number of factors, the variation in the specific heat and in the proportionality between heat radiated and temperature difference, and may even neglect for most practical purposes the variation in the resistance of the copper. The effect of the last named variation is in the opposite direction from that of each of the others and accordingly is very nearly counterbalanced by them. Tests show that the following law is quite closely obeyed:

$$x = T - \frac{T}{e^{ta}} \text{ or } e^{ta} = (10)^{2.3\,ta} = \frac{T}{T - x}$$

x is the rise in temperature after t minutes.

T is the temperature which would be attained by the cable after an infinite time, supposing in the calculation of this temperature that the same factors mentioned above are constant until the temperature is reached.

$$a = \frac{\text{temperature rise per minute at the beginning}}{\text{ultimate temperature rise}}$$

$$= \frac{\left(\frac{I \times 1000}{C.\ M.}\right)^2 \times 2.06}{T},$$

and is constant for a given conductor.

e is the base of Napierian system of logarithms.

This same type formula can be applied to insulated cables if we introduce an empirically determined constant, one which can be partly verified by theory.

The formulas then become

$$e^{ta/r} = (10)^{2.3\,ta/r} = \frac{T}{T - x}$$

The constant r represents the ratio between the heat which is stored in the entire cable and the heat which is stored in the copper.

The constant r varies with different styles of insulation and with the relative thickness and conductor. It also varies in the same cable, according to the time which is given for heat to penetrate into the insulation.

The constant r varies from practically one, with a very thin insulation, to three or more in a cable having a very small conductor with thick insulation. Based upon this formula and empirically determined values for r, we have calculated Table I given herewith.

To determine the time during which a three-conductor cable may carry a given per cent overload use the table as for a single-conductor cable having twice the cross-section area. For a two-conductor cable use the table as though for single-conductor cable of 50 per cent greater cross-section.

This table applies equally as well when the rating of a cable is changed by a change of temperature limit or by a change of initial temperature. The change in time for which an overload may be carried, caused by different thickness of insulation, will seldom be important. We have assumed in making the tables that 5/32-in. (3.97-mm.) insulation is used. The table applies approximately for any of the styles of insulation with which lead cables are now insulated.

TABLE I

OVERLOAD CARRYING CAPACITIES OF CABLES

	No. 6 B. & S. gage			No. 4 B. & S. gage			No. 2 B. & S. gage			No. 0 B. & S. gage		
	80%	50%	0%	80%	50%	0%	80%	50%	0%	80%	50%	0%
A Per cent	Time in minutes			Time in minutes			Time in minutes			Time in minutes		
200	0.6	1.3	1.8	0.8	1.6	2	1	2.2	2.9	1.5	3.1	4.5
175	0.9	2	2.7	1.2	2.5	3	1.5	3.2	4.5	2.3	5	6.5
150	1.6	3.2	4.5	2	4	5.5	2.7	3.5	7	4	8.5	10
125	3.5	7	8.5	4.5	9	11	6	12	15	9	16	20
	No. 000 B.&.S. gage			300,000 cir-mil.			500,000 cir-mil.			700,000 cir. mil.		
	80%	50%	0%	80%	50%	0%	80%	50%	0%	80%	50%	0%
Per cent	Time in minutes			Time in minutes			Time in minutes			Time in minutes		
200	2.1	4.5	6	3.2	7.5	9.5	5	10	13	6	12	15
175	3.2	6.5	9	5	11	13	7	14	17	8.5	16	22
150	5.5	12	15	9	16	20	12	21	26	14	26	33
125	13	23	28	18	31	39	23	40	45	28	50	60
	1,000,000 cir. mil.			1,200,000 cir. mil.			1,500,000 cir. mil.			2,000,000 cir. mil.		
	80%	50%	0%	80%	50%	0%	80%	50%	0%	80%	50%	0%
Per cent	Time in minutes			Time in minutes			Time in minutes			Time in minutes		
200	7.5	15	19	8.5	17	22	11	21	26	12	24	30
175	11	22	27	13	25	31	16	30	36	18	34	40
150	18	33	41	20	37	45	25	46	55	28	50	65
125	35	60	73	40	70	85	50	80	95	55	95	110

The data given are the lengths of time during which the loads given in the left-hand column can be carried, when the loads given in the first horizontal line of each table have been continuously applied previously to the application of the overload. Load is expressed in per cent of continuous carrying capacity, that is, normal load.

It must be noted that a considerable variation in the time frequently makes only a few degrees difference in the temperature This is most particularly true where the tables are hardest to interpolate closely.

Table II gives the time required to attain about 90 per cent of final temperature.

TABLE II

Size	Hours
No. 6	¾
1	1
No. 000	1½
cir. mils	
300,000	1⅔
500,000	2
700,000	2⅓
1,000,000	3
1,500,000	3¾
2,000,000	4½

It will require 50 per cent longer time to attain 97 per cent of final temperature and will require 50 per cent less time to reach about 68 per cent of final temperature.

The time given in this table may also be taken as the time interval which must elapse between overloads. If repeated oftener, the allowable duration of overload is decreased. If repeated at intervals of one-half this time, the allowable duration of overload is decreased 35 per cent.

We give an example of the use of these tables. It is required to determine the time an 800,000-cir. mil cable can carry 1200 amperes, when it carries continuously 400 amperes, its continuous capacity being given as 650 amperes. Express the loads as 185 per cent and 62 per cent of normal rating. We find from the tables that this load may be carried for about 11 minutes at intervals of 2½ hours.

For excessive overloads, we suggest that the temperature rise be calculated by the formula

$$\text{temp. rise} = \left(\frac{I \times 1000}{C.\,M}\right)^2 \times 1.15 \text{ deg. cent. per minute.}$$

The time required to reach the limiting temperature is then found directly.

SOURCES OF ERROR
IN
TRANSFORMER TESTS

BY

W. M. McCONAHEY and C. FORTESCUE

Presented under the auspices of the

Standards Committee

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SOURCES OF ERROR IN TRANSFORMER TESTS

BY W. M. MCCONAHEY AND C. FORTESCUE

Abstract of Paper

Only those errors that have an appreciable effect upon the results need be considered.

Instruments should be selected to give a reasonable scale deflection, should be calibrated at regular intervals, and should be used with discretion.

The use of instrument transformers should be avoided wherever possible. Stray fields seriously affect readings.

The ordinary tests that are made on transformers are enumerated and each one is considered separately. Sources of error in making these tests are pointed out and methods of avoiding or eliminating them are discussed.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26–28, 1913.

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(*Subject to final revision for the Transactions.*)

SOURCES OF ERROR IN TRANSFORMER TESTS

BY W. M. McCONAHEY AND C. FORTESCUE

In order to obtain accurate results in making transformer tests, it is necessary to make all measurements and tests very carefully, and to be able to pick out and eliminate all errors or sources of error. Some errors can be avoided, while others are of such a nature that they must necessarily be included in the measurements and can be corrected later. Only those errors or sources of error that have an appreciable effect upon the results should be eliminated, since to include all would be introducing laboratory methods into commercial testing, thus unreasonably increasing the time and cost of making tests without securing any useful results.

Instruments. Instruments should be selected to give a good scale deflection, as small errors in observation give a greater percentage error for small deflections than for large. They should be calibrated at regular intervals, and if at any time it is suspected that they have been subjected to abnormal usage, their calibration should be checked at once. Care should be taken that they are not used beyond their capacities, as in this way the calibration may be changed, or they may be damaged.

It is best to avoid the use of instrument transformers wherever possible, but when it is necessary to use them, they should be calibrated at the proper frequency, with loads equivalent to the instruments with which they are to be used.

Instruments should be located so as not to be influenced by stray fields. Neglect of this precaution may, in many cases, result in the introduction of serious errors. Careful note should be made of the way in which the instrument is connected in the circuit so that, when necessary, correction can be made for the losses that occur within the instrument itself.

Tests. Complete tests on transformers ordinarily include:

Ratio,
Polarity,
Resistance,
Iron loss and magnetizing current,
Copper loss and impedance,
Heat run,
Over-potential test,
Insulation test.

Each of the above tests will be considered separately.

Ratio. There is little difficulty in measuring the ratio of large power transformers. The number of turns is comparatively small and almost any convenient voltage may be used. Great care, however, must be used in order to get the correct ratio of small high-voltage transformers, and particularly those to be used with instruments. With the latter it is necessary that the ratio be correct within very narrow limits or the accuracy of the instrument readings will be seriously affected.

In measuring the ratio of small transformers with voltmeters in the ordinary way, it is necessary to apply practically normal voltage in order to secure accurate results. If only a small percentage of normal voltage be used, the drop due to the load of the measuring instrument alone will introduce considerable error. The most satisfactory way of measuring the ratio of such transformers is by paralleling them with standards of known ratio that have been specially designed with a large number of taps covering a wide range with very small steps. With a testing set of this kind, the ratio can be determined with a close degree of accuracy.

Polarity. The polarity of single-phase transformers is easily measured and requires no special precautions.

The polarity of three-phase transformers involves the relations between the phase displacement and the direction of the voltages at the terminals of the high-tension and low-tension windings, and the necessary measurements should be made to determine these relations. This can be best done by connecting one of the high-tension to one of the low tension terminals and impressing a convenient three-phase voltage across either winding and measuring all the combinations of voltages among the six terminals. From these, and a knowledge of the connections of the windings (whether delta or star), a voltage phase diagram showing the polarity can be constructed easily.

Resistance. The utmost care should be used in measuring resistance in all cases where it is used as a basis for determining the temperature rise. In measuring the cold resistance, it is just as important to know the actual temperature of the winding at the time the measurement is made, so as to get a correct basis from which to calculate the temperature at the end of the heat run.

Where the transformer is standing in the air, several thermometers should be placed in close contact with the coils at several points and, before making the measurement, time enough should elapse so that the temperature of the coils will be within a degree or two of that of the surrounding air. In order to secure the best results, the measurements should be made when the air temperature is steady, or at least showing very little fluctuation.

Where the transformer is in oil, it should be allowed to stand until thermometers show a practical agreement between the temperature of the windings and that of the oil.

In making the measurements, the readings should be taken as quickly as is consistent with accuracy, and the current should be small enough to avoid any appreciable heating of the windings. The temperature of the windings as shown by the thermometers, should be carefully noted at the same time.

Resistances can be measured most satisfactorily with a Wheatstone or a Kelvin bridge, the former being used for the higher, and the latter for the lower resistance. The resistance to be measured is generally known approximately, so that the bridge can be set fairly close to the correct point beforehand, and the time taken in getting the correct setting, when measuring the resistance at the end of the heat run, can be made very short.

Iron Loss and Magnetizing Current. The iron loss is a function of the frequency, the voltage and the voltage wave form. The frequency and voltage can be determined easily, but this is not true of the wave form.

Since the iron loss may be appreciably decreased or increased, according to whether the voltage wave form is peaked or flattened it is very desirable to have some satisfactory method of getting the proper correction to be applied to the wattmeter reading, so that the corrected result will be the same as would have been secured if the voltage wave had been of the sine form. It is possible to arrive at this by taking an oscillograph curve of the voltage wave when the iron loss is being measured, and analyzing and comparing it with the true sine form. This is a tedious operation, and one not suitable for commercial testing. A very satisfactory way of making the correction easily and directly is by using the iron loss voltmeter. This instrument gives at once the necessary correction without any calculation, and is therefore exceedingly useful for making iron loss measurements.

If the generator used in measuring the iron loss is large enough so that it is only lightly loaded, and if its voltage wave closely approximates the sine form, there will be very little wave distortion, and the correction to the wattmeter reading will be negligible. In order to make sure of this, however, it is best to use the iron loss voltmeter in all cases.

In a transformer having a large magnetizing current, the I^2R loss in the winding during the iron loss measurement may be appreciable. This loss is constant at all loads, and may therefor be properly included in the iron loss.

Due to the voltage drop in the primary winding, the induction in the iron will be slightly decreased in going from no load to full load, thus tending to decrease the iron loss slightly. On the other hand, the path of the leakage flux about the windings lies partly within the iron, and this may tend to increase the iron loss under load. On the whole, the net difference is negligible, and the iron loss may be considered the same at full load as at no load.

Copper Loss and Impedance. In making copper loss and impedance measurements, care should be taken to see that the frequency is correct and that practically no increase takes place in the temperature of the windings during the measurement.

The frequency affects the eddy current loss in the copper, and also the reactance, which varies directly with it.

Since the copper loss varies with the temperature of the windings, correct results can only be secured by maintaining the temperature at a practically known value during the measurement. This is secured by placing thermometers in close contact with the windings and letting them remain there until they show a steady temperature, and then taking the readings as quickly as possible.

Knowing the temperature of the windings at the time the readings are taken, the copper loss for any other temperature can be calculated with very little error, except where the eddy current loss is very large. In the latter case, it is best to take the copper loss at or near the temperature desired.

Distorted wave form of e.m.f. has very little effect upon copper loss or impedance, unless the distortion is very bad.

Heat Run. The heat run is made chiefly to ascertain the temperature rise under given load conditions.

In getting the temperature rise by resistance, great care must be taken in making the measurements, cold and hot, as discussed under " Resistance." Care must also be used in getting the temperature of the cooling medium or water.

For oil-insulated water-cooled transformers, the surrounding air has some effect upon the cooling, but it may be neglected. The temperature of the ingoing water is taken as the basis for calculating the temperature rise. The source of the water supply is generally such that its temperature remains practically constant during the heat run, so that the principal points to be observed are to see that a thermometer is placed in the ingoing water; that its readings are carefully recorded at regular intervals; that the flow of water is kept constant, and that practically an equal amount of water flows through all parallel coils. At the end of the heat run, the flow of water and the power should be shut off at as nearly the same instant as possible.

For air-blast transformers, the temperature of the air in the pit is the basis for calculating the temperature rise, and it should be maintained at a practically steady value during the heat run and particularly near the end. The dampers should be adjusted to give the proper flow of air, which is generally such as will show a temperature rise of 11 or 12 deg. in passing through the transformer. In shutting down at the end of the heat run, the air blast and the power should be shut off at the same instant.

In making a heat run on an oil-insulated self-cooling transformer, its temperature is determined by that of the surrounding air in the room. The room temperature is always a more or less variable quantity and hard to control, and should therefore be given careful attention. The room should be well ventilated, but strong air currents should be avoided. A steadily rising or steadily falling air temperature towards the end of the heat run introduces an error into the determination of the temperature rise that is not easy to eliminate. A satisfactory way to correct for the error is to have an unloaded transformer standing nearby and using the variation in the resistance of its windings as a basis for the correction.

Oil-insulated self-cooling transformers, when on heat run, should be separated by a space approximately equal to the width of the tanks. Thermometers should be placed about the transformers at a height that can be read conveniently, and far enough away not to be influenced by the radiation of the heat. This will generally require a distance of six feet (1.8 m.) or more from the transformers.

It has been the rule heretofore, to make a correction of one-fourth of one per cent in the temperature rise, as calculated from the resistance, for each degree of variation of air temperature from the standard of 25 deg. Experience, however, seems to show pretty conclusively that this is in error and that, for all practical purposes, no correction should be made.

Insulation Test. Before making this test, all the terminals of the high-tension winding, and also all those of the low-tension winding, should be connected together. Also, while testing between the high-tension and low-tension or ground, the low tension should be connected to ground. Otherwise, in testing between the high-tension and ground, dangerous stresses may be set up between the low-tension and ground far in excess of any that may occur in service, and a breakdown may result.

In making tests of about 50,000 volts or more, a spark gap should always be used. Because of the voltage rises that take the ratio of primary to secondary voltage of the testing transformer cannot be taken as equal to the ratio of turns, so that, without the spark gap, there is no measure to the actual testing voltage. A high resistance, sufficient to limit the flow of current to a small amount, should be placed in series with the gap.

Air bubbles in the oil about the transformer may be a source of serious trouble, and therefore, if there is any indication of their rising to the surface of the oil, the insulation test should not be applied until they cease. The test should be made immediately following the heat run, while the transformer is warm.

Over-Potential Test. This should be the last test applied. With high-voltage transformers, in particular, care should be taken to see that all terminals, connectors, etc., are in proper place. The frequency used should not be higher than is necessary to keep the magnetizing current within reasonable limits.

It is necessary in this test, also, that there be no indication of air bubbles in the oil.

MEASUREMENT OF TEMPERATURE IN ROTATING ELECTRIC MACHINES

BY

L. W. CHUBB, E. I. CHUTE and O. W. A. OETTING

Presented under the auspices of the

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MEASUREMENT OF TEMPERATURE IN ROTATING ELECTRIC MACHINES

BY L. W. CHUBB, E. I. CHUTE AND O. W. A. OETTING

Abstract of Paper

The paper discusses the advantages and disadvantages of standard and special methods of measuring temperatures, and also points out that the Standardization Rules on temperature tests are indefinite.

The maximum temperature affecting the insulation is the factor to be determined in the measurement of temperature of electric machines.

Thermometer and rise by resistance measurements have serious limitations under certain conditions, and the tests may either give erroneous results or must be carefully interpreted with due regard to the conditions under which they are taken.

Thermocouple and exploring coil methods are discussed in more detail, since their application in temperature testing of electric machines, is comparatively new. A very convenient method of employing thermocouples is described and results showing the heat distribution in an electric generator are given. These results not only are valuable to the designer of machines, but also present important data concerning the shut down of machines after temperature tests.

The question of the temperature of the air that actually cools a machine is discussed under "Room Temperatures." Thermometer measurements are further discussed in regard to their application to machines, showing the lack of uniformity of results on account of the various coverings and pads that may be used. The method of stopping the rotating element is also referred to in regard to taking shut-down temperatures.

The conclusion gives various recommendations to be considered in the revision of the Standardization Rules concerning temperature measurement.

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MEASUREMENT OF TEMPERATURE IN ROTATING ELECTRIC MACHINES

BY L. W. CHUBB, E. I. CHUTE AND O. W. A. OETTING

INTRODUCTION.

In some late papers* it has been pointed out that it is not the rise of temperature, but the ultimate temperature to which the insulation of electric machines may be subjected, that is the real limitation in the operation of such machines. Therefore, in the measurement of temperatures of electric machines, it is the temperature to which the insulation is subjected and not that of the copper and iron, which is desired.

In most cases, direct measurements of the temperature of the insulation in the hottest portion of the machine are practically impossible; in order to obtain reliable results of such temperatures, it is necessary to measure some adjacent temperatures and from these derive the desired results. The accuracy of such tests will depend, of course, upon the temperature measuring device, its nearness to the point to be measured and a knowledge of the temperature gradient between the point measured and the point at which the temperature is desired. In estimating the temperature gradient, it is necessary to consider the sources of heat, the direction of flow, and the thermal constants of the conducting parts which affect the distribution of heat.

In electric machines the temperatures of the two faces of any of the insulation will be very nearly the same as that of the adjacent parts, and the temperature of this intervening insulation will be between these limits (except in rare cases of high dielectric losses). For example, the insulation on an armature

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*C. E. Skinner, Proceedings Association of I. & S. E. E., Oct. 1912
B. G. Lamme, PROCEEDINGS A. I. E. E., Vol. XXXII, No. 1.

coil will have the local copper temperature on one side and the local iron temperature on the other side. One or the other of these may be the higher depending upon the relative losses in the iron and copper, the ventilation, and the conductance of the adjacent paths of heat flow. If at all points throughout the length of the slot the iron is hotter than the copper, then the hottest point of the insulation can be measured directly by mean to be described later. If the copper at any point is hotter than the iron, it is fair to assume that the hottest coil insulation is next to the copper at the center of the slot. The temperature measurement that can be taken is on the outside of the coil at the center of the slot, and to obtain the maximum temperature of the insulation it is necessary to make allowances for the temperature gradient through the insulation.

Obviously the ordinary methods of measuring temperatures give no exact indication of the distribution of the heat inside of electric machines. Heretofore special methods of measuring temperatures have been considered impractical and almost impossible. Recent developments, however, show that internal temperatures of electric machines can be readily obtained, especially those of stationary parts.

PRESENT STANDARD METHODS OF MEASURING TEMPERATURES

1. *By Thermometers.* This is the most common method in use. Its chief recommendations are its availability, simplicity and cheapness. Its usefulness is limited to the temperature measurement of the external parts of a machine. Consistent results can be obtained by this method, provided the conditions under which it is used remain the same. On these conditions depends entirely the proper interpretation of the results, for any conclusion based on past experience is reliable only in so far as the basis of that experience remains unchanged. Wide variations in temperatures will be obtained depending on the location of the thermometers and the method of application to the part in question. Sluggishness is an inherent characteristic and must be kept in mind in any application of thermometers. These limitations will be discussed further under methods of applying thermometers.

2. *By Rise of Resistance.* This method is applicable only to the windings of the machine and obviously represents only an average result, not distinguishing the hot portions from the cold. For windings of high resistance, such as field coils, fairly good

results may be obtained by this method. Although the resistance measurement does not represent the hottest part of the coil since there is a temperature gradient from the center of the coil to the outside surface, yet in most field coils this gradient will not be excessive, so that the average temperature while below the maximum will still be a close indication of the safety of the coil.

In the case of low resistance windings the results obtained are far from satisfactory. In the first place laboratory methods and apparatus are required to obtain results with any degree of reliability. Variations of contact with temperature are continually entering in, offsetting the accuracy of even the most reliable measurements. The proper interpretation of correct measurements here is much more difficult than in the case of field coils of high resistance. With the winding passing through several zones of temperatures, the average value of the temperature is but a slight indication of what may be existing in the various parts. For instance, if the end windings of an armature are well ventilated so that the temperature of part of the end copper is but little higher than that of the air, there may be a small portion of the coil buried in the core which is at a considerably higher temperature, and yet have but little influence on the total resistance of the winding. Again, a portion of the end windings may be so packed together and so completely covered by bands, that the relative temperature rise in this part is high, while the armature core and the buried copper is at a relatively low temperature. This condition was brought rather emphatically to the attention of some of us in the case of a large revolving field generator. The rises by resistance on the various tests were consistent and bore a reasonable relation to the thermometer temperatures, the maximum value being 45 deg. cent. However, on opening the windings it was found on several of the coils that the insulation surrounding the portion buried in the bottom of the slot had been heated to a much higher temperature than that indicated by the rise of resistance method.

Perhaps the most unsatisfactory results obtained by this method are those pertaining to the windings of the armatures of direct-current machines. Temperatures thus obtained are inconsistent and the least said about them the better.

SPECIAL METHODS OF MEASURING TEMPERATURES

1. *By Exploring Coils* (Resistance Type). This method of measuring temperatures depends on the fact that resistance of

most materials varies with the temperature of the material. There are several methods in use for measuring the resistance of such coils, any of which gives results with a fair degree of accuracy. Most of these methods have many complications which are liable to involve inaccuracies. There have been special indicators devised, however, that enable these measurements to be made directly and with very few complications. Bulbs of special forms (suitable for various applications) are manufactured and may be inserted at any point where it is desired to measure temperature. These bulbs are made with either three or four leads which connect to suitable binding posts on the indicators. The indicators have a variable resistance which is adjusted until the galvanometer of the indicator reads zero. This variable resistance is adjusted and calibrated so that the temperature is read off direct from the scale on the indicator. The whole apparatus is convenient for reading temperatures quickly and accurately.

The chief drawback of this method is the expense of the exploring coils. For high temperatures, platinum resistance coils are used and for lower temperatures, coils of nickel wire. These coils must all be carefully adjusted and calibrated. Likewise the same leads must always be used in conjunction with a certain exploring coil; so that if these leads are broken or if it is necessary to increase the length of the leads, the calibration of the instrument is changed and the correct temperature cannot be obtained unless a new calibration of the coil is made. To obtain a coil of small size, such as must be used within the slot of an electric generator, a considerable amount of fine wire must be used to obtain the necessary resistance. This makes the exploring coil frail and is apt to cause breakage.

2. *By Thermocouples.* Another convenient method of measuring temperatures is by means of thermocouples. This method is used largely in high temperature measurements where thermometers cannot be used. However, it has not been applied in low temperature measurements to any great extent because, until recently, there were no readily portable indicating instruments sensitive enough to give accurate results without troublesome corrections or special adjustments of the thermocouples. To obtain temperatures by this method the e.m.f. of the couple may be measured by a millivoltmeter or by the potentiometer method. This latter method is very accurate and can be used in portable form to read temperatures to a higher degree of accuracy than the ordinary thermometer. Fig. 1 shows a diagram of con-

nections of the instrument which was used in all the tests to obtain the data of internal temperatures which are given in this paper.

B is an ordinary dry battery supplying a very feeble current to the potentiometer circuit made up of the potentiometer wire P, a variable resistance R_v, and the resistance R. S is a special rocker switch with spring so made as to be connected between a and g on one side and c and h on the other, when neither side of the rocker switch is depressed. If the switch is depressed on side g, connection is made between g and b. This causes a current to flow in the circuit made up of galvanometer G and resistance R_s. The deflection on G gives a measure of the current in the potentiometer wire P. The resistance R and R_s are so adjusted and the galvanometer G is so calibrated that the current is at the proper value when the needle of the galvanometer reads the micro-volts per deg. cent. for the couple that is used in measuring the temperature. With the current set at this value the spring contact again connects a and g when the rocker switch is released. This connection substitutes Rg for the galvanometer G; and since Rg is made equal to the resistance of G, the current in the potentiometer wire P remains unchanged.

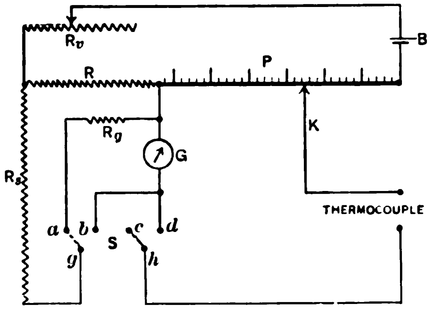


FIG. 1

Now to obtain the temperature on the thermocouple, the other side of the rocker switch is depressed which connects d and h. This puts the couple, the galvanometer G, and a part of P in series (the couple being so connected that its e.m.f. " bucks " that of P). Contact K is run along the drum holding the potentiometer wire P until galvanometer G reads zero. The result is read off on a scale along the wire P, which scale can either be calibrated in millivolts or some arbitrary unit. If a couple is used that has a linear calibration curve between temperature and e.m.f., the wire *P* can be calibrated directly in degrees of temperature. A couple made up of steel and advance wire gives a calibration curve that is practically a straight line up to temperatures well above those obtained in electric machines.

The accuracy of this method depends on the sensitiveness of galvanometer *G* and the length of the scale divisions on potentiometer wire *P*. The unipivot galvanometer is very satisfactory for this work, giving a meter that is portable, at the same time beng extremely sensitive. The calibration of the potentiometer wire can be made very accurately by using a large number of turns of wire wound around a drum. With the instrument used in this test, seven turns of wire gives a range of 150 deg. cent. and each graduation on the scale indicates to two-tenths of a deg. cent.

The great advantage of these thermocouples, like the exploring coils, lies in the fact that they record the actual temperature of the body with which they are in contact and can be applied where it is impossible to locate thermometers. The couples can be made to respond to changes of temperature almost instantly by rolling the junction flat so as to present a large heat absorbing area and diminish conduction along the leads. A large factor in favor of the thermocouple method with a potentiometer is the utter independence of resistances or lengths of leads; for when the temperature is read by the instrument, the galvanometer reads zero and no current flows; so the resistance in the circuit has no effect whatever.

One thing is quite needful in this method, however, and that is a sensitive galvanometer. The e.m.f. of the couple is small, especially for low temperatures; so to get accurate results, the galvanometer should be sensitive enough to respond quickly to small changes of e.m.f. Another precaution necessary is to see that the material of the couple wires is uniform. It is safe, however, to assume that all the wire on a small reel is of uniform structure, and only one calibration is necessary for each reel.

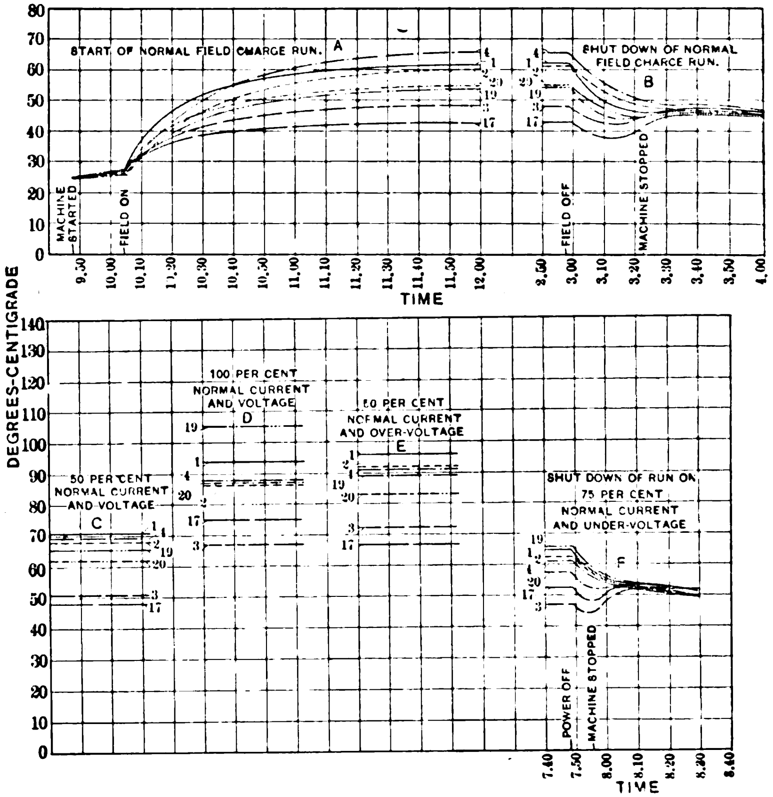
The use of thermocouples (likewise, resistance exploring coils) cannot be recommended for taking temperatures on revolving parts during the rotation of that element. To take such temperatures it is necessary to use slip rings and brushes. The number of such couples is limited by the space available for the slip rings. The mechanical equipment necessary, especially on machines of high peripheral speed, make the test extremely expensive, and the results obtained are so questionable that this test cannot be recommended. A better method is to fasten thermocouples on the rotating element at different places where the temperatures are desired allowing the leads to be exposed in some places where there will be no interference with the rotation of the machine. On the shut-down of the machine, leads from the measuring instrument can be clamped on these thermocouples and the temperatures read immediately. Readings of temperatures can be taken at different intervals of time; so if the time is taken between shut-down and the first reading of temperature, the temperature curve can be exterpolated to the actual running temperature of the couple before shut-down. This eliminates all the slip ring trouble and gives a very close indication of the running temperatures in the rotating element.

An interesting series of tests was made on a revolving field generator showing the comparison of various internal temperatures of both the iron and the copper. Thirty-two thermocouples were placed in the machine; sixteen between laminations in various positions and sixteen in the slots on the coils of the machine. Leads from these different couples were brought out to a special switch and so arranged that any one of the couples could be placed on the measuring instrument and the temperature read. By this means, at least six different temperatures could be obtained in a minute's time. Thus it was possible to get results of temperature at these thirty-two points of the machine, which results, when plotted, showed the heating and cooling during the beginning and the shut down of each run and also the constant temperatures when the machines had reached their maximum temperature during the run.

Fig. 2 gives a summary of this series of tests showing seven of the principal temperature curves that were taken. *A* shows the heating of the machine at the beginning of a field charge run. Of course, it is reasonable to suppose that the laminations will become hotter than the coils in a run of this nature. *B* shows the shut down of this test. When the field was removed from the machine, there was no braking effect to stop the rotating except the friction of the bearings and the windage, and the friction of the brushes on the commutators of two driving motors. It is interesting to note the various temperatures. Couple No. 17, located between a coil and a wedge, cools until the rotation almost ceases; then it becomes warmer again, because the ventilation due to the rotation ceases and the hotter parts of the machines warm the air in the gap, which causes the temperature of couple

No. 17 to rise. This effect is shown also to a lesser degree on No. 3, which is near an air duct in the iron.

C, *D* and *E* of this figure show the maximum temperatures of several other tests. *F* shows the machine shut down as in *B*, but



1— In iron 1/2 in. below top of tooth in center of package.
2—In iron 1/2 in. below bottom of slot in center of package.
3.—In iron 1/2 in. below bottom of slot next to air duct.
4—In iron 4 in. below bottom of slot in center of package.
17—In slot between coil and wedge.
19—In slot between coils.
20—In slot between side of coil and iron.

FIG. 2

under somewhat different conditions. A load was on during this run and when the power was removed, the field of the machine was reduced to one-half, instead of being removed entirely as in *B*. Thus the rotation was stopped in eight minutes time, about one-third of the time as required in test *B*. The curves show the temperature equalizing again in the same manner. These results bring up the question " What is meant by ' shut-down ' temperatures?" Obviously very different results would have been obtained on these two tests *B* and *F* if thermometers had been placed on the machine after the rotation had ceased. This point will be discussed later under " Method of Stopping Rotating Element."

Present Standardization Rules Indefinite

1. *Room Temperature.* This term enters into practically all contracts for electric machines and its meaning should be so clear as to be beyond dispute. The temperatures of air foreign to the machine can have no effect on the machine's temperature; it is the air that immediately surrounds a machine that is effective; or in case of machines artificially cooled, it is the temperature of incoming air. Even under these limitations there is still too great a latitude for dispute. Thermometers so placed as to be affected by the outgoing air are even more undesirable than those placed at considerable distance from the machine tested. It seems that there is no absolute rule adaptable for every case, but certain general limitations may be suggested; such as the maximum distance from the machine which may be expressed in terms of the diameter of the rotating part, or the thermometers must be so located as to indicate either the temperature of the still air surrounding the machine or else that entering it. Local conditions frequently demand special consideration, such as the effect of the temperature of poorly ventilated pits on the parts effected. In such a case the average temperature surrounding the machine is as foreign in its effect on the local parts as that of the north pole on the equator. In the case of a certain 8770-kv-a. generator in a large hydroelectric plant, this local effect was as much as 10 deg. cent. In another case, safe limits were far exceeded until the pit was properly ventilated, when the temperature of the part in question at once became normal.

2. *Method of Applying Thermometers.* As previously stated, the inferences deduced from thermometer measurements depend upon the duplication of conditions. This applies especially to the application of thermometers. The methods used depend considerably on the nature of the temperature to be measured. These may be divided into two classes: those pertaining to stationary parts, and those pertaining to rotating parts.

In the stationary parts, all thermometers may be located before the start of the test, and as the temperatures increase gradually there is no special difficulty in the thermometer following very closely. In the larger machines, the thermometers should be protected from the windage of the machine, or other drafts, by a small covering. This may be of putty, clay or felt. Some persons prefer one and some another. Putty is rather soft at working temperatures. Clay makes a very good holding medium when carefully put on, but our experience has been that more uniform temperatures, and usually higher results as well, are obtained with the felt. On windings this covering may be in the shape of a small sleeve, the bulb being exposed only on one side; the whole being tied to the coil securely with twine. On iron laminations a small felt pad about 1½ by 1½ in. (3.8 by 3.8 cm.) glued to the surface under which the thermometer is inserted seems to give the best results. This method also has proved satisfactory when used on the larger copper conductors. The pad must not be too large as a hot spot may be created, neither must it interefere with the radiation of the machine. On smaller machines, the liability to hot spots becomes much greater and either a very small ball of clay is to be preferred, or else the thermometers should be left bare and treated after shut-down as described below for thermometers on the rotating parts. On these machines a thermometer will not give the correct maximum values while the machine is running, but will indicate when the machine has reached a constant temperature.

The method of obtaining temperatures of rotating parts by thermometers presents quite a different problem. A very wide range of results may be obtained on account of variations due chiefly to the method of getting the heat from the body, whose temperature is to be measured, to the thermometer bulb. The thermometer bulb can be so placed, with respect to the copper in the coil, that the resistance in the heat conducting path to the bulb is much greater than desirable. For instance, if a thermometer is simply laid on the coil, whose temperature is to be measured and covered with a little waste, and another thermometer is placed on the coil and provided with a seat made of tin foil, two different results will be obtained. Obviously, with metal seat, a larger amount of heat in a given time can be conducted from the coil across the insulation and thence to the bulb, than would be the case without the metal seat; for the section of the heat conduction path through the insulation is increased and the average length of the path shortened. However, if the dissipation of conduction of heat from the point to be measured to other parts of the winding is relatively slow, both thermometers should eventually indicate the same temperature. If, however, the heat dissipation is rapid, either by conduction to the air or to other parts of the winding, the thermometer which gives the quicker reading should reach a higher temperature. In a certain instance it was found that the thermometer provided with a metal seat reached this maximum six minutes before one simply laid on the winding, both being protected from the air in the same manner. The discrepancy in temperature was eight degrees, the cooling curve of the machine in question falling rapidly. Thermometers are sluggish in their action and they take a certain time before they come up to temperature. So in similar conditions as mentioned above, if thermometers are applied which have previously been heated to about the same temperature of the machine, higher results of temperature will be obtained than if the thermometers had not been heated before application to the machines.

Thus, all these methods of applying thermometers will give results that in no way will be comparable. There must be a definite ruling as to the manner of applying thermometers so as to obtain comparative results.

3. *Method of Stopping Rotating Element.* Another point which causes dispute is the method of bringing the rotating element to rest after a temperature run. Should the machine be allowed to rotate without any load until all the flywheel effect is expended or should the magnetic field be used to retard the machines, or should the machine be braked mechanically by means of pulleys and ropes to stop it more quickly? It is quite evident that the fanning effect of the rotating element lowers the temperature of the machine very rapidly. The curves shown in Fig. 2 show temperatures in a machine which had sufficient flywheel effect to allow it to rotate freely for a period of 22 minutes after the load was removed. It is obvious, considerable variation will result in the temperature obtained if the time of bringing the rotating element to rest is varied. For instance, from the curves of the normal field charge run in Fig. 2, it is seen that there is a considerably greater drop in temperature in the 22 minutes than in five minutes. So if the machine had been stopped in five minutes by mechanical braking, higher shut-down temperatures on the rotating element would have been obtained. In another case when mechanical braking was resorted to, temperatures 10

degrees warmer were obtained when shut down in 1½ minutes than when shut down in six minutes.

CONCLUSION

It is evident from the foregoing discussion that the proper interpretation of temperature results depends almost entirely upon the conditions of tests and upon the temperature measuring method employed. No one method is suitable in every case. The thermocouple and exploring coil are generally applicable; but the thermometer and rise by resistance methods are preferable in many cases because of convenience, simplicity and inexpensiveness.

The experience of the authors has prompted the following recommendations in regard to taking temperatures of electric machines:

1. Thermometers should be used to measure all temperatures of exposed parts, the temperature of which is constant or is not changing too rapidly for the thermometer to follow.

2. In cases where the part to be tested is small, and the thermometer and covering may distrub the thermal conditions, the thermometer should not be used.

3. The application and covering for thermometer bulbs should be standardized.

4. The rise by resistance method should be used to measure only the temperatures of windings which are known to be at a rather constant temperature throughout, such as transformer coils, field coils, some stator windings, etc.

5. The rise by resistance method should not be used for windings or parts of windings of very low resistance.

6. Thermocouples or exploring coils may be used to measure temperatures of internal parts, especially in machines with long cores, such as high speed turbo-generators, and also in parts where steep and doubtful temperature gradients make it impossible to draw any definite conclusions from thermometer temperatures or rises by resistance.

7. Exploring coils are either expensive, or require expensive adjustments and laborious calculations for tests. Thermocouples are preferable to exploring coils in commercial testing.

8. If internal temperatures are required in revolving parts, thermocouples may be used and readings taken after shut-down. Running temperatures with slip rings and brushes cannot be recommended.

9. Temperatures which will be affected by the permanent application of a thermometer or a pad may be taken by the momentary application of a quick responding thermocouple.

10. The rises of temperature should be based on the temperature of the *cooling air*. The determination of the cooling air should be standardized as far as possible.

11. A convenient and probably the best method of stopping a machine after a temperature run, is by field excitation. Whenever possible full field should be used to stop the machine quickly and thus maintain the temperatures.

It is hoped that more definite rulings can be established in regard to temperature tests. A temperature obtained within a machine by means of a thermocouple or an exploring coil may not meet guarantees as specified in the present Standardization Rules. In addition to specifying the methods to be used, the limiting temperatures must be considered in each case.

THE EXPERIMENTAL DETERMINATION OF THE REGULATION OF ALTERNATORS

BY

A. B. FIELD

Presented under the auspices of the

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THE EXPERIMENTAL DETERMINATION OF THE REGULATION OF ALTERNATORS

BY A. B. FIELD

Abstract of Paper

The method of determining the regulation of an alternator from test results which is incorporated in the Standardization Rules, is not accurate for low power factors, as it takes no cognizance of varying pole leakage or of the ratio of armature reaction to reactive voltage drop. The effects of these are most marked at power factor zero, and as this is also the only power factor at which a load regulation curve can usually be experimentally determined satisfactorily, it is advocated to base regulation determinations upon the power factor zero load saturation, and the no-load saturation.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26-28, 1913.

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(*Subject to final revision for the Transactions.*)

THE EXPERIMENTAL DETERMINATION OF THE REGULATION OF ALTERNATORS

BY A. B. FIELD

The section of our Standardization Rules* which deals with alternator regulation has remained in force practically unchanged for the past ten years. When this was originally drawn up, it was generally customary to specify the regulation for non-inductive loads, and for this condition, the suggestions contained in the rules are satisfactory; the rules, however, are not explicitly restricted to non-inductive loads, and when at a later date the regulation for lower power factors began to be more frequently the subject of specification, the same methods of computation from test results were naturally followed. It has been somewhat of a superstition for many years, although now rapidly dying out, to put an undue importance upon the regulation of a-c. generating apparatus, upon the equality of regulation of machines which are to run in parallel, and so on. It is now well recognized that greater adaptability of the machine to occasional operation at over-voltage, excess current, and lower power factors, is more value than a comparatively close regulation, the combination of the two properties being seldom commercially feasible. Other considerations also have arisen which call for higher regulation rather than low. As an illustration of the earlier attitude may be cited the fact that the A. I. E. E. rules for the determination of the regulation have been accepted readily by the same purchasers who specify closely a given regulation and are inclined to base acceptance or rejection of apparatus upon the supposed regulating qualities within a narrow margin, although the *real* regulation on, say, an 80 per cent power factor load, may vary considerably from the figure anticipated by one who applies the methods of Section 209, and the variation is in the direction of higher regulation.

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*Section 209 in the 1907 and 1911 editions and Section 71 in the 1902 edition.

To review the situation very briefly, let us consider the regulation at zero power factor, a characteristic more easily checked experimentally, than the regulation at any other power factor. According to Section 209, we obtain the zero power factor saturation curve from the no-load saturation curve by shifting this over, parallel to itself, a given distance horizontally, the vector addition of excitations being the same as arithmetical addition when the power factor is zero; (see Fig. 1.) This is equivalent to representing the effect of the load as a simple demagnetizing action on the field magnets, while we know that, to put it at its simplest, we have the combination of a demagnetization and a reactive voltage drop, which would suggest moving the no-load saturation curve over parallel to itself, not horizontally, but in an inclined direction, the inclination being determined by the ratio of reactive drop to the demagnetizing action (see Fig. 2). It should be noted that these two give the same results only for a no-load curve which has no saturation bend.

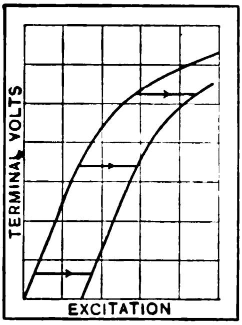

FIG. 1

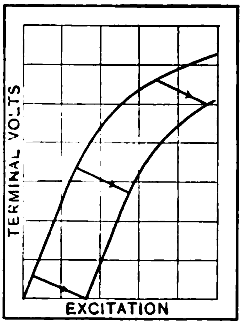

FIG. 2

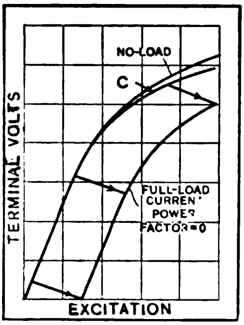

FIG. 3

As a matter of fact, this method again will give an approximately correct result only when the percentage pole leakage is small, or when the load considered produces a demagnetizing effect upon the armature which is small compared with the ampere-turns of the air gap and teeth.

To obtain a closer approximation to the load saturation curve for zero power factor, deduced from the no-load and short-circuit curves, we must lay out an auxiliary no-load saturation curve with increased pole leakage (curve C in Fig. 3) and move this curve parallel to itself horizontally by an amount corresponding to the armature demagnetizing ampere-turns, and vertically downwards by an amount corresponding to the armature reactive voltage drop. The amount of pole leakage for curve C is determined approximately by considering (A) the armature demagnetizing ampere-turns, and (B) the magnetizing ampere-turns for the air gap plus armature laminations. The ratio

$\frac{A + B}{B}$ is the factor by which the no-load pole leakage is to be multiplied in order to obtain that for curve C. With this procedure the experimentally determined zero power factor saturation can generally be checked fairly closely.

As a matter of fact, the *general shape* of the load saturation curve, within the range that we are usually concerned with, closely resembles that of the no load saturation curve; that is to say, if the curve be transferred to a piece of tracing paper and laid on top of the no-load curve, a position can be found in which they nearly fit one another. This indicates that by using a *fictitious* armature reaction and reactive voltage drop for the method of Fig. 2, a compromise inclination can be found for the direction in which to move over the no-load curve, and obtain the zero power factor curve. If the curves have been experimentally determined, the inclination can be found readily by moving the load curve horizontally to the left till it passes through the origin, thus matching the no-load curve over the initial straight part, and then moving it up in the direction of the initial slope until the higher points also agree. This process is followed in Fig. 4, where, taking a fairly high point P on the load curve, we set out $P\,Q$ to the left, equal to $O\,R$, and then draw $Q\,S$ parallel to the initial part of the saturation curve. It will be found that the distances between the two curves measured parallel to $S\,P$ are nearly constant, provided we do not push the method to points too high up on the curves. The distance $O\,R$ is obtained from the direct short-circuit curve for the load current in question, and a few high points on the load curve enable us to construct the curve fairly well.

It should be noticed that the actual drop in voltage on inductive load, with a given saturation and a short-circuit curve, depends upon the inclination of $S\,P$, and therefore is not determinate from the saturation and short-circuit curves alone.

Further information is required, preferably the experimentally determined saturation curve for full-load current at a power factor nearly zero. To illustrate this graphically, there are given in Fig. 5 the no-load and short-circuit curves of two generators which, when plotted to suitable scales, practically coincide. However, the pole leakage of one machine is a more prominent feature than in the case of the second machine, and we have a correspondingly lower load saturation curve. Both machines are of modern type and construction and have the same number of poles, and the curves are plotted from test figures slightly adjusted to bring them to a comparable load basis. It will be seen

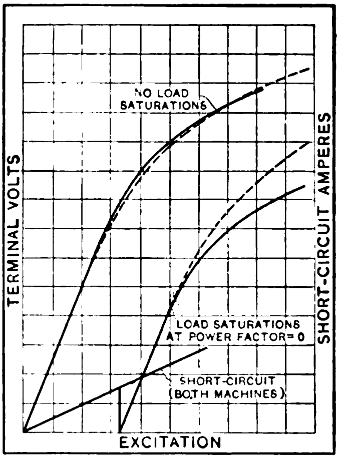

FIG. 4

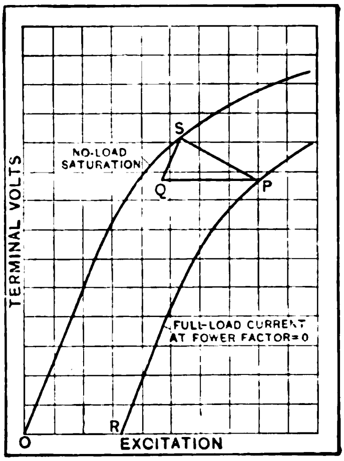

FIG. 5

that, in spite of the coincidence of the no-load and short-circuit curves, the zero power factor curves do not coincide, except on the straight parts at low voltages.

RECOMMENDATIONS

This memorandum upon regulation has been written merely to introduce a discussion upon the subject. In order to have a definite basis to start from, the author suggests that this Institute make the following recommendations:

1. That the regulation of alternators for power unity, be specified only in those cases in which the actual operation of the plant may be expected to be at a power factor very near unity, and then only when conditions make the regulations a feature of importance.

2. That for alternators which are to operate at power factors of 85 per cent or below, it should be recognized that the actual value of the regulation (which is necessarily high) is of minor importance, and that when it is desired to specify regulation for power factors below 80 per cent, it is preferable to do so for power factor zero, since this can be directly checked experimentally on the manufacturers' test floor in many cases, while the regulation at higher power factors cannot be so checked, except for very small machines. The operating regulation will always be lower than the zero power factor regulation for a given ampere load.

3. That when it is desired to determine experimentally the regulation at a given load, and at power factors between unity and zero, for machines which cannot be actually loaded at the desired power factor, it is preferable to do so from the experimentally determined saturation curves for no-load, and for the given ampere load at zero power factor.

4. That to determine the load saturation curve for a given power factor from these two curves, it may be assumed, for uncompensated alternators, that at any excitation value the drop in voltage between no-load and zero power factor load is equivalent to a reactive drop, which may be treated vectorially for the power factor in question. The armature ohmic voltage drop may similarly be treated vectorially, but generally has a negligible effect upon the regulation at power factors below unity.

5. That for the experimental determination of the load saturation curve at zero power factor, any power factor below 20 per cent may be assumed to be equivalent to power factor zero.

CONCLUSION

In conclusion, the author wishes to direct attention to a paper* on this subject presented ten years ago before the Institute in connection with the revision of the clauses on regulation in the Standardization Rules. That paper drew attention to the importance of the zero power factor curve, and showed the relation between this and the no-load saturation as outlined above. The revision of Section 209 can advantageously be based upon the conclusions submitted there.

**The Experimental Basis for the Theory of the Regulation of Alternators*, by B. A. Behrend, TRANSACTIONS A. I. E. E., 1903 XXI, p. 497,

CORRECTION ON TRANSFORMER TEMPERATURES FOR VARIATION IN ROOM TEMPERATURE, TAKING INTO ACCOUNT BOTH COPPER AND IRON LOSSES

BY

C. FORTESCUE

Presented under the auspices of the

Standards Committee

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CORRECTION OF TRANSFORMER TEMPERATURES FOR VARIATION IN ROOM TEMPERATURE, TAKING INTO ACCOUNT BOTH COPPER AND IRON LOSSES

BY C. FORTESCUE

ABSTRACT OF PAPER

Assuming that loss of heat takes place only by convection, formulas are derived for obtaining the corrected temperature rise of a body consisting mainly of copper for any arbitrary room temperature. Similar formulas are derived for bodies consisting of both iron and copper. It is shown that when the effects of both the iron and copper loss in a transformer are taken into account, this correction is so small that it is of the same order as the probable errors of observation, and may generally be neglected. When other factors are considered, this correction is still further reduced. If the effect of radiation also be taken into account, the probable correction is reduced to zero, or may even be negative where the rules indicate positive corrections.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26-28, 1913.

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CORRECTION ON TRANSFORMER TEMPERATURES FOR VARIATION IN ROOM TEMPERATURE, TAKING INTO ACCOUNT BOTH COPPER AND IRON LOSSES

BY C. FORTESCUE

I. Introduction

When the temperature rise of a coil of copper wire is to be measured by the increase of resistance method, it is generally required that the calculated rise above actual room temperature be corrected to give the rise corresponding to a standard room temperature, *e.g.*, the rise which would have resulted if the room temperature were 25 deg. cent. It usually happens that the temperature of the room differs from the generally accepted standard of 25 deg. For this reason the rise in temperature is found under actual conditions of the test and then a correction is made which depends upon the difference between the actual room temperature and the standard room temperature.

It is proposed in this paper to derive first of all an expression for the corrected temperature rise, for any arbitrary room temperature, of a body consisting mainly of copper, based on the assumption that the heat loss takes place mostly by convection, and in comparison the amount lost by radiation is negligible. Lastly, an expression will be obtained for bodies consisting of both iron and copper immersed in a fluid medium which is cooled by air. It will be shown that with both iron and copper losses taken into account, the difference between the observed temperature rise and that corrected for the standard room temperature is very small and even when convection alone is taken into account, it may be considered, as a rule, negligible.

Within the ordinary range of temperatures, there is the same increase in the resistance of a copper wire for each degree increase in temperature. The change in resistance caused by a change of one deg. cent., expressed as a fraction of the resistance at a definite standard temperature, is termed the temperature coefficient. The increase in resistance per degree is 0.00428 of the resistance at a temperature of zero deg. cent. Hence the resistance at any other temperature may be found by multiplying the number of degrees above zero by the coefficient and adding the result to the resistance at zero. The increase for each degree is 0.00386 of the resistance at 25 deg. cent. Therefore, the resistance at a higher temperature may be found by multiplying the number of degrees increase by this coefficient and adding the result to the resistance at 25 deg. These statements call attention to the difference between two coefficients which are in common use.

From the above definition of the temperature coefficient is derived the following well-known rule for calculating the temperature rise of a copper conductor above its initial temperature when the initial and final resistances are given, viz.:

$$t_2 - t_1 = \frac{R_2 - R_1}{R_1} (233.2 + t_1) \tag{1}$$

where t_1 is the initial or room temperature, t_2 the final temperature and R_1 and R_2 the initial and final resistances.

II. CORRECTED RISE OF COPPER CONDUCTORS

The simple formula given below for determining the corrected rise of a coil carrying a current of constant value, is in its general form adapted to obtain the rise corrected for any arbitrary room temperature, when values of the initial and final resistance for any other room temperature are given. It is derived on the assumption that the rise in temperature above that of the surrounding air, of an air-cooled conductor carrying a given current, is proportional to the rate of dissipation of energy at the final temperature. The formula may be stated as follows:

$$t_b - t_a = \frac{R_2 - R_1}{R_1} (233.2 + t_a) \tag{2}$$

where t_a is the arbitrary room temperature and t_b the temperature that would be reached by the apparatus if run in a room having this temperature. The formula applies to naturally cooled apparatus consisting of copper conductors, provided that the effect of radiation can be considered negligible, but with proper modifications may also be used for artificially cooled bodies.

A simple statement of the formula, applicable to every room temperature, may be made as follows: If a number of similar coils of copper wire in rooms, kept at different constant temperatures, carry equal and constant currents throughout a heat run, and the temperature of each body and that of the room in which the run is made is, in each case, the same at the start, the percentage increase in resistance, when steady temperatures are reached, will be the same for each of the coils.

When the observed temperature rise under any condition of room temperature is given, that for any other room temperature may be found by the formula

$$t_b - t_a = (t_2 - t_1)\,\frac{233.2 + t_a}{233.2 + t_1} \qquad (3)$$

Here $(t_2 - t_1)$ is the observed rise for the test room temperature t_1, and $(t_b - t_a)$ is the corrected temperature rise based on a room temperature t_a.

Substituting 25 deg. cent., the A. I. E. E. standard room temperature, in equation (**2**), the following simple statement of the correction formula is obtained:

If the resistances are given,

$$\text{(temperature rise of body above standard room temperature)} \\ = \text{(observed percentage increase in resistance)} \times 2.582 \qquad (4)$$

If the observed temperatures are given

$$\text{(temperature rise of body above standard room temperature)} \\ = \left(\frac{258.2}{233.2 + \text{observed room temperature}}\right) \\ \times \text{(observed rise)} \qquad (5)$$

The derivation of formulas (**2**) and (**3**) is as follows:

From the assumed law of cooling, the following relations may be derived:

$$K\,(t_2 - t_1) = R_2\,I^2 \qquad (6)$$

$$K\,(t_b - t_a) = R_b\,I^2 \qquad (7)$$

where K is a factor depending on the surface of the body and its heat conductivity, I is the current in the conductor and R_b is the final resistance corresponding to the temperature t_b.

From the definition given for temperature coefficient, it follows that

$$\frac{R_b}{R_2} = \frac{233.2 + t_b}{233.2 + t_2}$$

and therefore, by (**6**) and (**7**),

$$\frac{t_b - t_a}{t_2 - t_1} = \frac{233.2 + t_b}{233.2 + t_2}$$

$$= \frac{233.2 + t_b - (t_b - t_a)}{233.2 + t_2 - (t_2 - t_1)}$$

$$= \frac{233.2 + t_a}{233.2 + t_1}$$

whence is derived formula (**3**)

$$t_b - t_a = (t_2 - t_1)\, \frac{233.2 + t_a}{233.2 + t_1}$$

Substituting from (**1**), formula (**2**) is obtained.

$$(t_b - t_a) = \frac{R_2 - R_1}{R_1} (233.2 + t_a)$$

To illustrate this formula by an example, take the case of a body composed of copper wires run in a room whose temperature is 35 deg. cent. throughout the run; the observed final resistance when a steady temperature is reached is 20 per cent higher than the initial resistance; to determine its temperature rise corrected for a room temperature of 25 deg. cent.

Here the temperature rise obtained by test was 53.6 deg.

Applying formula (**4**), the corrected rise is found to be 20 × 2.58 = 51.6 deg. cent.

The above formulas have been derived on the assumption that the rate of dissipation of heat from a body by convection is directly proportional to the difference in temperature of the body and the air. This law is commonly referred to as " Newton's law of cooling." If the effect of radiation is negligible and there is a free circulation of air, and its temperature is not raised appreciably after leaving the body, this law holds good. For bodies cooled by air flowing through constricted paths, such as air-cooled transformers, the average temperature of the coils will depend upon the average temperature of the air in the ducts, and the difference between these two values will depend upon the rate of dissipation of heat; but the average temperature of the air in the ducts, on account of the larger flow at the higher difference of temperature between coils and air obtained with higher room temperature, will not be proportional to the rate of dissipation of heat. In such cases the correction obtained by formula (**3**) will be too great.

The formulas (**2**) and (**3**) are suitable only in bodies whose external radiating surface is very small compared with the surface reached by convection currents. They will therefore apply to bodies cooled by forced convection. If the body is to be cooled by natural air circulation and has a smooth external blackened surface, so that the heat lost by radiation becomes appreciable, the formulas will give corrections very much too high, or even, in some cases, indicate a positive correction where it should properly be negative.

III. CORRECTED RISE CONSIDERING BOTH COPPER AND IRON

It will be noted that the formulas which have been developed for obtaining corrected temperature rise by the increase of resistance method apply only to electrical apparatus composed wholly of copper conductors, or where the copper part of the apparatus may be considered separately from the rest on account of being heat-insulated from it. For air-cooled bodies consisting of both iron and copper, as, for instance, generators, it is very difficult to obtain a correction formula for room temperature; but in the case of apparatus in which both copper and iron are cooled by a common medium, such as oil, it is possible to obtain an approximate expression for corrected rise. Considering the case of oil-insulated air-cooled apparatus, such as oil transformers, let t_1 = initial room temperature, t_2 = final temperature of the copper, t_a = standard room temperature, t_b = corrected temperature. Let corresponding values of R be designated by R_1, R_2 and R_b; let R_0 = resistance of body at 0 deg. cent., and let W be the iron loss. Then approximately,

$$K\,(t_2 - t_1) = I^2 R_2 + W \tag{8}$$

$$K\,(t_b - t_a) = I^2 R_b + W \tag{9}$$

$$\frac{t_b - t_a}{t_2 - t_1} = \frac{I^2 R_b + W}{I^2 R_2 + W}$$

$$= \frac{\dfrac{I^2 R_0}{233.2}\,(233.2 + t_b) + W}{\dfrac{I^2 R_0}{233.2}\,(233.2 + t_2) + W}$$

$$= \frac{\dfrac{I^2 R_0}{233.2}\,[(233.2 + t_b) - (t_b - t_a)] + W}{\dfrac{I^2 R_0}{233.2}\,[(233.2 + t_2) - (t_2 - t_1)] + W}$$

$$= \frac{\dfrac{I^2 R_0}{233.2}\,(233.2 + t_a) + W}{\dfrac{I^2 R_0}{233.2}\,(233.2 + t_1) + W}$$

$$t_b - t_a = (t_2 - t_1)\,\frac{I^2 R_a + W}{I^2 R_1 + W} \tag{10}$$

This may be stated in the following words:

In air-cooled electrical apparatus composed of copper conductors and iron, immersed in a common medium, in which the copper carries a current of given value and the iron is subjected to a periodically changing induction of given magnitude, the temperature rise, when steady conditions are reached for any arbitrary room temperature, may be obtained from that calculated for any other room temperature, by multiplying this observed rise by the ratio of the total losses at the arbitrary and the given room temperature.

The observed rise at the room temperature of the test may be either that obtained by thermometer or by the increase in resistance method, using formula (**1**).

When it is desirable to obtain a closer approximation than that given above, the following procedure may be followed.

First, obtain the average temperature rise of the oil or common cooling medium above the test room temperature and correct to standard room temperature by formula (**10**). Next obtain the average rise of copper above the average temperature of the oil under test conditions and correct to the corrected oil temperature by equation (**3**); the sum of these two will give the temperature rise of the copper corrected to standard room temperature.

Applying the formula to a practical example—An oil-insulated air-cooled transformer has copper loss, at 25 deg. cent., 1000 watts, iron loss 1000 watts. At a room temperature of 35 deg. cent. the oil rose to an average of 25 deg. above the air. The average temperature of the copper above the oil was 15 deg. cent. What is the corrected average temperature rise of the copper at a room temperature of 25 deg. cent.?

Total loss at 25 deg. cent. = 2000 watts

Total loss at 35 deg. cent. = 2038 watts

$$\text{Corrected rise of oil} = \frac{I^2 R_a + W}{I^2 R_1 + W}(t_2 - t_1)$$

$$= \frac{2000}{2038} \times 25 = 24.5 \text{ deg. cent.}$$

Corrected average rise of coils above average temperature of oil

$$= \text{observed rise} \times \frac{233 + \text{corrected oil temp.}}{233 + \text{observed room temp.}}$$

$$= 15 \times \frac{233 + 49.5}{233 + 60} = 14.45 \text{ deg. cent.}$$

Corrected temp. rise of coils above air = 38.95 deg. cent.

The observed value was 40 deg. cent.

Thus, even when cooling by convection of air only is taken into account, the correction is so small as to be negligible in most cases. In fact, the correction is, as a rule, less than the probable errors in observation.

It has been assumed in the deduction of formula (**10**) that the average temperature rise of the oil is proportional to the total heat dissipated. This would be true only if the rate of flow of the convection currents of oil were constant. As a matter of fact, the oil will flow faster as the temperature rise of the coils above the oil increases. The flow will also be inversely proportional to the viscosity of the oil, which decreases as its temperature increases. The correction, therefore, given by the above rule, is always too great, and if, in addition, the heat lost by radiation on account of the higher coil temperatures reached with higher room temperature be taken into account, the correction will probably be reduced to zero, and, in some cases, instead of a positive correction as assumed in the rules, a negative correction may be necessary.

NOTES ON METHODS OF MAKING LOAD TESTS ON LARGE INDUCTION MOTORS

BY

A. M. DUDLEY

Presented under the auspices of the

Standards Committee

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NOTES ON METHODS OF MAKING LOAD TESTS ON LARGE INDUCTION MOTORS

BY A. M. DUDLEY

ABSTRACT OF PAPER

This paper gives a description of the methods ordinarily employed in making actual load tests on large induction motors. From this follow the reasons for making compromise temperature tests and enumeration of some of the methods more commonly employed. Comments are made on these various schemes, followed by five examples comparing the results of temperature tests under actual load conditions with results of compromise tests made on the same machines. The conclusion is drawn that compromise temperature tests are desirable and necessary and should have recognition in the Standardization Rules.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26-28, 1913.

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NOTES ON METHODS OF MAKING LOAD TESTS ON LARGE INDUCTION MOTORS

BY A. M. DUDLEY

It is desirable, wherever it is possible, to test apparatus fully in all respects before it leaves the premises of the manufacturer. Where this can be done and the results carefully checked by both parties to the contract there is little possibility of the units failing to do in service what was expected of them.

In the case of induction motors such complete tests include a check on the efficiency, power factor, torques, heating, noise, mechanical balance and temperature. With the exception of temperature, it is possible to make observations with the motor at standstill or running under no load which will indicate closely to the trained observer what may be expected of the machine, with reference to the different characteristics enumerated. It is also true to a degree that these same observations give the losses in the various parts of the motor and in this way are a check on the temperature. This check is more evident to the designer, on account of his experience with the amount of loss that his various frames will dissipate, than it is to the man of less experience who represents the ultimate user and who is endeavoring to satisfy himself that the machine in all respects meets the specifications to which the manufacturer is working. For this reason it is desirable to load up the motor to as nearly exactly its normal operating condition as can be reached and make observations of the temperature rise in the various parts.

In the case of motor-generator sets driven by induction motors which come through manufacture in pairs, it is possible by the simple expedient of circulating the power around through all the machines, to secure full load temperature tests on four machines at an expense merely of making up from an outside circuit an amount of power represented by the losses of the four units. It is also possible, in the case of separate units coming through in pairs, to make a full load run at a reasonable expense. This may be accomplished in at least two ways. The first depends on the mechanical connection between the two units at the time one is running as a motor and the other as a generator. In practise this is worked out by belting the two machines together with a pulley on the unit which is to act as a motor, slightly larger than the pulley on the unit which is to act as a generator. When the machines are started up and both are connected to the same source of alternating-current supply there is a tendency for one machine to drive the other slightly above synchronism due to the difference in pulley diameters. If this difference has been chosen or can be adjusted so that it is approximately twice the full load slip of the units when running normally, the result will be that the combination will automatically divide this difference on either side of synchronous speed and one will run fully loaded as a motor below synchronism and the other fully loaded as an asynchronous generator above synchronism. Since the generator returns to the circuit all the power taken by the motor, with the exception of the full load losses in both machines, this method is economical. It has the disadvantage practically that it is difficult to select or adjust the pulley diameters exactly as they should be.

The same result can be accomplished electrically by having available two sources of alternating current supply, which can be adjusted so that the frequency of one will be slightly higher than the other. The two units undergoing test are then directly connected by some form of positive coupling and the motor unit is connected to the current supply which is to be higher in frequency. The generator unit is then connected to the source of lower frequency and since it runs at the same rev. per min. as the motor, it is really running above synchronous speed as referred to the circuit to which it is electrically connected. The two sources of external power supply are then adjusted with just the proper difference in frequency to cause both the tested units to run under full load conditions, one as a motor and one as an asynchronous generator. As the two sources of external power supply are presumably from a common source still further back, it is possible to balance up the consumed and regenerated energy so that only the full load losses of the two tested machines need be supplied externally. This method works out very satisfactorily and is frequently employed in making such tests.

Two units are not always available, and in that case, if the machine to be tested is one of large capacity, it may be difficult or impossible to make a full load test. The reasons for this are obvious. The manufacturer may not have available the necessary mechanical facilities in the way of shafting, bearings, pulleys, belts or gears to line up the motor so it can be loaded or there may be no suitable machine to serve as a load for the tested motor or to drive the tested motor as a generator, and last but by no means to be considered negligible, the expense of conducting such a dead load test, from the standpoint of the power consumed alone, would be considerable. For example, a unit of 1000 h.p. would have a full load input in the neighborhood of 800 kw. and this load for ten hours at one cent per kw-hr. would amount to $80.00.

For these practical reasons it is necessary in such cases to adopt some form of compromise test, which, while it may not give exactly the same results as actual full load, will give a sufficiently close approximation to judge the actual temperatures under operating conditions after installation.

There are a number of different methods of accomplishing this result, of which the following may be mentioned.

1. Operating the unit under test as a motor on normal frequency but at reduced voltage and developing a reduced torque.
2. Driving the tested unit as an a-c. generator by a small auxiliary motor and making compromise tests after the methods followed on a-c. generators. These may consist of over-exciting one member with direct-current so as to give high iron losses, or using a lower excitation with the other member short-circuited so as to give high copper losses.
3. Operating the tested unit as a motor without load but at a voltage higher than normal in the effort to increase the iron and no-load copper losses to a sum approximating the full-load copper and iron losses.
4. Operating the tested unit as a motor on a cycle where it will alternately run light for a period at over-voltage and for another period at low voltage and a light load sufficient to cause full load or somewhat greater current to flow in the windings.
5. Connecting the tested unit to a supply circuit at a greatly reduced voltage and driving it against its normal direction of

rotation by a separate motor. By varying the voltage applied it is possible to cause any desired current to flow in the windings, with proportionate heating.

Considering these methods in order, they will be found to give the following results:

1. In this case it is possible to get full-load copper losses but there is necessarily only a small proportion of the full-load iron loss present. The copper losses may be increased to approximate the iron loss but the losses so created are distributed differently from those in the normally operated and loaded machine and the resulting temperatures are affected thereby. Such tests ordinarily show the copper temperatures higher than normal and the iron temperatures somewhat lower.

2. These tests are similar in every way to the same tests conducted on a-c. generators. As is shown in Table V, in some cases they give results very close to the tested values under actual load.

3. This method resembles method (1) in the fact that the distribution of losses is different from the normal machine. This test usually shows the iron temperatures too high and the copper temperatures too low. There is a practical limit to the amount the voltage may be increased, due to the limits of the insulation.

4. This test, with a proper selection of the proportion of total time for the various parts of the cycle and the frequency of their alternation, can be made to give results very closely approximating full load conditions. It is hardly safe, however, to adopt a general cycle as applicable to all machines, on account of the varying proportions of copper and iron losses in machines of different characteristics. Data on this method, where available, indicate very satisfactory results.

5. This method has proved very satisfactory in a large number of instances. It is, however, open to criticism in that it imposes on the rotor core a frequency of about twice the normal primary frequency. This does not occasion any material error from the standpoint of iron loss in the rotor core, since the applied primary voltage and the resulting densities are fairly low. It does, however, occasion considerably increased rotor copper losses due to eddy currents caused by the high secondary frequency. As shown in Tables I and V, this is ordinarily of no consequence on 25-cycle machines. Tables II, III and IV show, however, that it may materially increase the rotor temperatures on 60-cycle machines and through these, the temperatures of the whole

machine. One of the advantages of this method is that it is safe, *i.e.*, it shows temperatures on test which are higher, if anything, than they will be under actual load conditions. It may, therefore, be concluded that, if a machine has been operated in this way and the temperatures are within specified limits, the temperatures under normal operating conditions will be within the same limits. Unfortunately, the converse is not equally true, *i.e*, a machine may show under this test temperatures which are higher than the specified limits and which under actual load conditions may be well inside these same limits. But this is a good fault in any compromise method and should not detract from the excellent results which follow generally from its use.

As the writer's experience has been more largely in connection with method (5), he offers in the tables some typical examples of tests conducted in this way. In every case the columns marked " circulating current " are tests taken in this way, *viz*: a current of normal frequency and greatly reduced voltage is applied to the motor terminals and it is driven against the normal direction of rotation at full-load speed. The applied voltage is then varied until the desired current flows in the windings.

TABLE I
INDUCTION MOTOR—PHASE-WOUND ROTOR

Rating: 1000 h.p., 25 cycles, three-phase, 2200 volts, 12 poles, 245 rev. per min.

Losses.

Primary copper	11,600 watts
Secondary copper	13,800 "
Core loss	7,700 "
Bearing friction and windage	6,400 "
Total	39,500 watts

TEMPERATURE DATA

Kind of load	Actual load driving generator			Circulating current
Length of test in hours	8	2	7½	8½
Volts	2247	2220	2240	360
Per cent normal full -load amperes	139	170	150	139
Rise, in deg. cent., stator core	31	40.5	36.5	29
" stator copper (thermometer)	33.5	47.5	39	38
" " " (resistance)	36.5	48.2	—	34
" rotor copper (thermometer)	24.5	38.5	34	32
" " " (resistance)	33	32.6	—	35
" rotor core	24	34	28	25
Amperes per phase	312	390	341	312
Air temperature, deg. cent	18	18.5	16	21

TABLE II

INDUCTION MOTOR—PHASE WOUND ROTOR

Rating: 300 h.p., 50 cycles, three-phase, 550 volts, 16 poles, 367 rev. per min.

Losses.

Primary copper	5950 watts
Secondary copper	5050 "
Core loss	4900 "
Bearing friction and windage	3200 "
Total	19,100 watts

TEMPERATURE DATA

Kind of load	Actual	Circulating current
Length of test in hours	3	2
Volts	550	158
Per cent full load amperes	128.5	128.5
Rise, stator core, deg. cent	25	38.5
" " copper (thermometer)	23.5	36.5
" " " (resistance)	30.1	42
" rotor " (thermometer)	23.5	30.5
" " " (resistance)	25.2	38.5
Amperes per phase	373	372.5
Air temperature, deg. cent	20	30.5

TABLE III

INDUCTION MOTOR—SQUIRREL-CAGE ROTOR

Rating: 300 h.p., 60 cycles, three-phase, 2200 volts, 6 poles, 1160 rev. per min.

Losses.

Primary copper	4125 watts
Secondary copper	7500 "
Core loss	9140 "
Bearing friction and windage	4000 "
Total	24,765 watts

TEMPERATURE DATA

Kind of load	Actual belted	Circulating current
Length of test in hours	11½	2
Volts	2196	326
Per cent of full load amperes	103	129
Rise stator core deg. cent	40.5	29.5
" " copper (thermometer)	25	28
" " " (resistance)	30.6	34.4
" rotor " (thermometer)	26.5	52.5
Rev. per min	1160	1155
Amperes per phase	71	88.8
Air temperature, deg. cent	23.5	23

TABLE IV

INDUCTION MOTOR—PHASE-WOUND ROTOR

Rating: 800 h.p., 60 cycles, three-phase, 2200 volts, 26 poles, 272 rev. per min.

Losses.

Primary copper	10,500	watts
Secondary copper	10,000	"
Core loss	14,000	"
Bearing friction and windage	7,700	"
Total	42,000	watts

TEMPERATURE DATA

Kind of load	Actual	Circulating current
Length of test in hours	7¼	7¼
Volts	2260	456
Per cent full-load amperes	126	102
Rise, stator core, deg. cent	42.5	36
" " copper (thermometer)	36.5	37
" " " (resistance)	44.5	41
" rotor " (thermometer)	26.5	50
" " " (resistance)	28	48.6
" " core	24.5	43.5
Amperes per phase	266	214
Air temperature, deg. cent	16.5	23

TABLE V

INDUCTION MOTOR—PHASE-WOUND ROTOR

Rating: 1600 h.p., 25 cycles, three-phase, 6400 volts, 6 poles, 492 rev. per min.

Losses.

Primary copper	17,300	watts
Secondary copper	18,200	"
Core loss	13,200	"
Bearing friction and windage	18,000	"
Total	66,700	watts

TEMPERATURE DATA

Kind of load	Actual		Circulating current	Rotor excited with d-c. and stator short-circuited	
Length of test in hours	5½	5½	6¼	7½	8
Volts	6360	6300	950	0	0
Per cent full-load amperes	102	130	104.8	100	125
Rise, stator core, deg. cent	24.5	29.5	18.5	19	28
" " copper (thermometer)	23.5	31.5	25	19	35.5
" " " (resistance)	34.3	48	30	30	49.5
" rotor " (thermometer)	23	28	32.5	24	37.5
" " " (resistance)	28.5	35	34	—	62
" " core	19	20	25	16	26
" collector	22	22	22.5	23.5	31
D-c. volts on secondary				43	58
D-c. amperes in secondary				487	643
Air temperature, deg. cent	21	23	23.5	21.5	21

Table I. This is a fair example of the results of this method. A comparison of columns 1 and 4 run with the same current input shows remarkably close results for a compromise method. Any slight inaccuracies which may be noted are due to using commercial test results and to a policy on the author's part of avoiding carefully edited laboratory readings.

Table II. In this machine, operated on 50 cycles, can be noted the tendency for the high rotor frequency to heat up the rotor and through it the complete machine. It will be noted that the test was at approximately 28½ per cent overload.

Table III. This test was at 60 cycles, and while an actual load of 103 per cent is compared with a compromise at 129 per cent it can be seen that the rotor on the compromise test ran at a higher temperature than would be the case with the same amount of actual load.

Table IV. This case shows the extreme variation of the compromise method and was on a machine where the depth of the rotor conductors was sufficient to magnify considerably the eddy current loss due to secondary currents at a frequency of approximately 120 cycles.

Table V. This is an interesting comparison and shows the results of compromise tests made by two methods, enumerated as (2) and (5) above, and the performance of the same machine under actual load. The results of all three tests were satisfactory, but the compromise results were, of course, secured with considerably less effort and expense than was true in the case of the actual load tests.

CONCLUSIONS

From these considerations are drawn the following conclusions:

1. That the employment of a compromise method of making temperature runs on induction motors of large capacity is in many cases desirable and necessary.

2. That the method outlined above as method (5) gives results which are always " safe " and which are in general a close approximation to the actual temperatures.

3. That it is desirable that the Standardization Rules of the American Institute of Electrical Engineers should recognize the various methods of conducting such compromise tests, together with their reliability and limitations as applied under varying conditions.

THE CALIBRATION OF THE SPHERE GAP VOLTMETER

BY

L. W. CHUBB and C. FORTESCUE

Presented under the auspices of the

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THE CALIBRATION OF THE SPHERE GAP VOLTMETER

BY L. W. CHUBB AND C. FORTESCUE

ABSTRACT OF PAPER

Under certain conditions the breakdown of the air gap between equal spheres is very constant and that the sphere gap which has already been suggested as a standard for high voltage measurements has been found to be more reliable than the usual methods of test.

Different methods of measuring high voltage are discussed and a new method of reading the maximum value of high voltage circuits is described.

The method used in calibrating three sets of spheres in terms of maximum voltage is given.

The results of many tests show the breakdown voltage to be independent of wave shape and frequency when expressed in terms of the maximum value of the voltage wave.

Direct calibrations are shown for 25-cm., 37.5-cm., and 50-cm. spheres up to a voltage (max. value) of 400 kv.

The relation between surface intensity at breakdown and ratio of separation to diameter shows the ultimate strength of the air to vary from 30 to 36.6 kv. per centimeter within the working range.

The theoretical proportion between voltage, separation and diameter of spheres did not hold, apparently because of extraneous objects.

Calibration curves are shown for the 25-cm. 37.5-cm. and 50-cm. spheres, from low voltage up to the voltage corresponding to a diameter separation. The curves are expressed in effective value of voltage and therefore assume a sine wave shape.

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THE CALIBRATION OF THE SPHERE GAP VOLTMETER

L. W. CHUBB AND C. FORTESCUE

The breakdown strength of air between spherical terminals has been found to be rather constant and the sphere gap has been suggested as a standard instrument to be used in the measurement of high voltage. Results obtained with different apparatus by different experiments, however, have not been in perfect accord and the ultimate dielectric strength of air indicated by calculating the maximum intensity from these tests, has shown some calibrations of the gaps to disagree with results obtained by other methods.

If spheres of sufficient size are used and if the separation and breakdown voltage is such that there is no corona at the surface of the spheres, it is fair to assume that the complete breakdown of the air gap will occur at the voltage at which the stress due to the intensity at the surface of the spheres corresponds to the ultimate strength of the air. It also seems as though the rupture of a given sphere gap should be independent of frequency of time of voltage application, and that it should depend only upon the maximum value of the voltage impressed, provided that there is no ionization before breakdown which in effect alters the shape of the terminals and changes the dielectric gap.

The purpose of this paper is to present the calibration curves for the three sizes of sphere gaps which have been suggested as standards.*

To be of value in measuring voltage, the sphere gap must be furnished with a calibration curve showing the relation between the breakdown voltage and length of gap. The results of any calibration can be no better than the method used in the test, and unless such calibration is accurate the sphere gap voltmeter is not a desirable standard.

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*See paper by Farnsworth and Fortescue, p. 299 of this issue of the PROCEEDINGS.

Different methods used to calibrate spark gaps at high voltage show great variations in the relation between voltage and separation of spheres. Some also show a great variation with frequency. It can be shown that such differences are due to conditions of test rather than to any real variation of the sphere gaps themselves.

The most usual method of measuring the high tension voltage is to measure the primary potential and multiply by the ratio of the transformer. Voltages obtained by this method are generally very much in error, due to the distributed capacity in the high-tension winding of the transformer, harmonic distortions of the applied voltage wave, and the capacity of the terminal bushings and the apparatus to which the high-voltage winding is connected. The effective, or r.m.s., low-tension voltage is usually indicated so that there is no measure of the maximum unless a pure sine wave of voltage is applied, there are no appreciable distortions due to the harmonic components of the exciting currents, and the capacity regulation can be corrected.

The use of a second high-voltage transformer to step down the voltage for measurement with a voltmeter, is an improvement over the straight ratio method, but requires corrections in most cases, and another expensive transformer.

Another method of measuring the high-voltage which has been used by the authors is to connect an electrostatic voltmeter of low electrostatic capacity in parallel with one or several sections (at the ground side) of a condenser type terminal. This method corrects the reactive errors of the ratio method but is also an effective reading and gives no indication of wave shape and maximum value.

The calibration of the sphere gaps was thought to be dependent only on the maximum voltage and it was the aim of the authors to obtain the calibrations in terms of maximum of the voltage of the high-tension winding, and then reduce the results to effective values assuming sine wave shape of voltage.

A very satisfactory method of measuring the maximum of the voltage wave was to rectify the capacity current taken by an air condenser and measure the average value of the rectified current with a d'Arsonval galvanometer. The details of this method will probably be of interest.

Fig. 1, shows diagrammatically the apparatus and circuits necessary to calibrate the gap in terms of the maximum voltage.

The air condenser is shown in Fig. 2. It was constructed of wood carefully turned to dimensions and coated with tin foil and lead sheeting. The central and high voltage member was 60 cm. (23.6 in.) in diameter and 458 cm. (15 ft.) long. The outside or ground member with the flared ends had a total length of 240 cm. and internal diameter of 162.8 cm. (5.34 ft.) It was divided into three sections, the middle or working part was 47.7 cm. (18.8 in.) long and the end sections or guard rings were each of equal length in the cylindrical part and were flared with toroidal surfaces having a radius of 47.7 cm. (18.8 in.). The capacity of the central section was figured and found to be $2.657 + 10^{-11}$ farad.

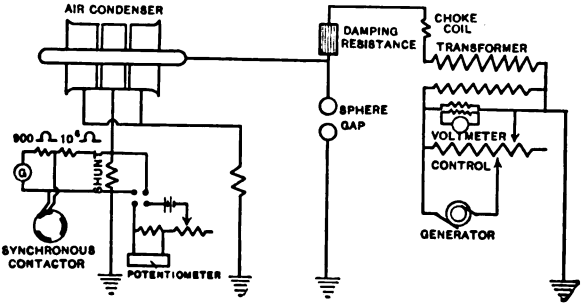

FIG. 1

The central section of the outside member was connected to ground through a non-inductive resistance which served as a shunt to measure its charging current. The guard ring sections were connected together and grounded through a resistance of such a value that the time constants of the center and ends would be approximately the same, and there would be no cause for leakage between the three sections. Across the resistance between ground and the central section was connected the galvanometer circuit consisting of a megohm of series resistance and a d'Arsonval galvanometer shunted with a synchronous contactor. The contactor was driven by a six pole synchronous motor and arranged with three equal brass segments which short circuited two brushes during every alternate half cycle. The brushes were connected to a long lever so that they could be readily shifted in phase. A maximum deflection of the galvanometer in this case indicates commutation at the zero points of the current wave and this maximum deflection was proportional to the average charging current of the condenser section and also proportional to the maximum voltage impressed upon the condenser.

If Q is the quantity required to charge the condenser to any maximum potential V, the passage of $2Q$ is required to change the potential from $+V$ to $-V$ for the symmetrical periodic charge. While the potential changes from $-$ V to $+V$, the reversal of current is suppressed in the instrument by the shunting effect of the synchronous contactor. The steady deflection of the instrument is therefore, caused by a unidirectional pulsating current. The average value of the condenser current(disregarding sign) is equal to the quantity flowing, in coulombs per second.

$$I = 4\,Q\,f = 4\,C\,V\,f \qquad (1)$$

where C = Capacity of condenser.
f = Frequency.
V = The maximum voltage.
and I = The average value of the condenser current.

The steady current deflection (d) of the galvanometer is

$$d = K\,I \qquad (2)$$

where K is the instrument constant in divisions per ampere. From (**1**) and (**2**)

$$V = \frac{d}{4\,C\,K\,f}$$

In all cases the value of K was obtained by applying the battery voltage to the galvanometer circuit while the contactor was running.

In order to make sure that the contactor was making good contact at all times frequent check tests were made with the contactor running, and still to make sure that currents for equal deflections were in the ratio of 2 to 1. The galvanometer was critically damped so as to obtain quicker readings, and to eliminate errors due to overshooting and swinging which would occur with voltage variations and phase shifts. With the instrument underdamped it was difficult to distinguish between voltage variations and false setting of the brushes. When overdamped the proper position of the brushes for the maximum reading could readily be found, when the voltage was steady, but the response to quick changes in voltage was not sufficient, and it

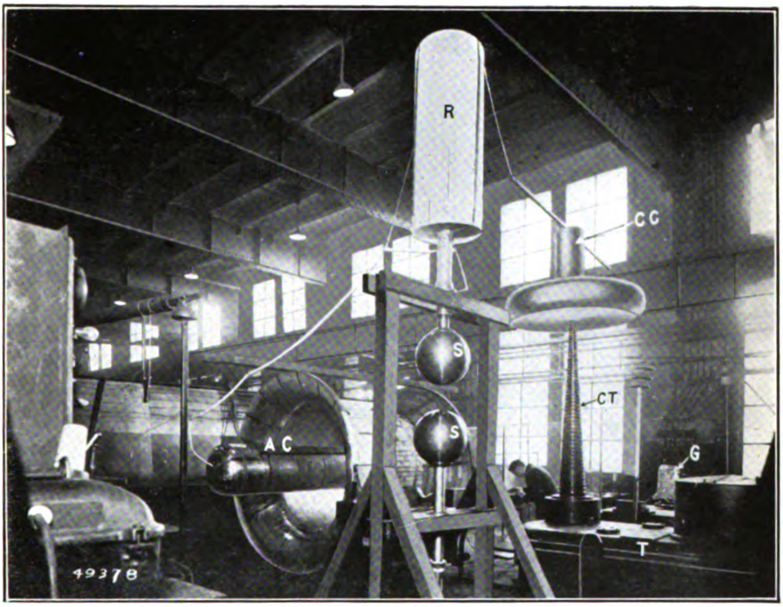

FIG. 2. [CHUBB AND FORTESCUE]

T—Transformer; C T—Condenser terminals; C C—Choke coil; R—Resistance; S S—Sphere gap; A C—Air condenser; G—Galvanometer.

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was impossible to tell whether the breakdown of the gap was due to a surge of voltage or not. Throughout the work, all wiring, instruments, switches, resistances in the circuit, and the contactor were shielded with grounded coverings of tinfoil or wire screen in order to remove static troubles. Serious errors were introduced when any part of circuit was left unshielded, but the strong static field had no bad effects when the shields were properly grounded. There was an appreciable capacity between the high tension terminal and the ground side of the condenser, and in order to prevent errors due to this additional condenser current, through the measuring shunt, it was necessary to place a grounded network of wires between the condenser and the high-potential circuits. Before each test a high voltage was applied, with the condenser disconnected and short circuited, to find out if there were any static or electromagnetic troubles which would give a deflection of the galvanometer. If no such troubles were present the high tension lead was connected to the condenser and tests made as follows.

The gap was opened two or three cm. beyond the breaking point. Voltage was then applied to the condenser and gap. After the maximum deflections of the galvanometer had been carefully observed the sphere gap was very slowly closed until breakdown occurred. The maximum value of the voltage was then worked out from the galvanometer readings and a direct-current calibration made after each test. The relation between this maximum voltage and the separation of the spheres was then plotted.

In the later tests the contactor was driven with a 30-h.p. induction motor instead of a synchronous motor. By making this change both positive and negative maxima could be observed, and no shifting of brushes was necessary as the adjustment for maximum deflection was obtained each time the rotor of the motor had slipped a pole pitch. At 60 cycles, the motor slipped less than one revolution (6 poles) per minute so that with the critically damped galvanometer, accurate observations of the two maxima could readily be made. At lower frequency the per cent slip was of course greater but the frequency of galvanometer maxima was about the same.

Tests were made at frequencies ranging from 25 to 60 cycles with two high-voltage transformers, each excited from two different sources of power.

The authors hoped to calibrate the 37½-cm. and 50-cm. spheres to 500 kv. (effective) on a third and larger transformer, but lack of time and a great volume of commercial testing delayed these tests.

It was assumed that a good test on the 25-cm. spheres up to the voltage corresponding to a diameter separation could be made on the 300-kv. transformer and the calibrations of the larger gaps obtained by exterpolation and the theory of proportional fields.

If the calibration of the 25-cm. spheres showed a constant surface intensity throughout, and if the larger set agreed within the same range of voltage such an exterpolation could not be questioned. The results however, show increasing intensity with an increase in separation, and show the air between the larger spheres to be apparently weaker than between the small spheres for the same ratio of separation.

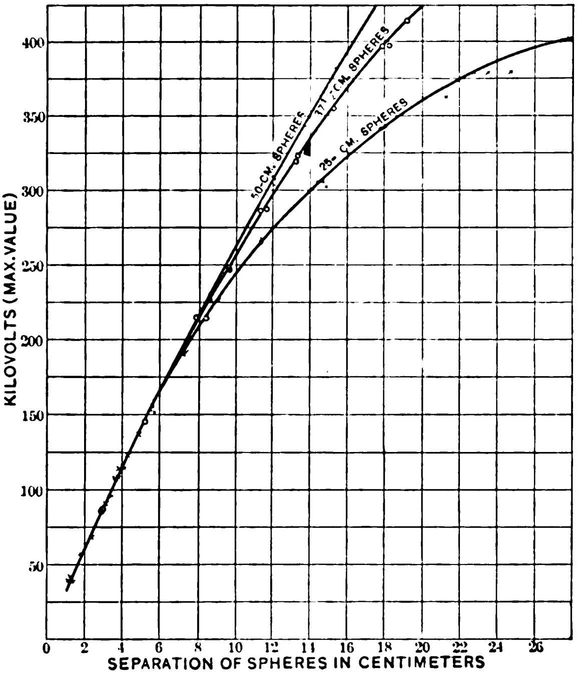

FIG. 3

The increase of surface intensity with increase in separation has been observed by several experimenters, but not satisfactorily explained. The relative weakness of the air gaps between the large spheres is probably due to the effect of neighboring bodies.

Extraneous objects at constant distances from the gaps will of course weaken the gap between the larger spheres more than that between the smaller spheres. Quantitative tests of the effect of extraneous objects will be made later.

The results of the tests show frequency and wave shape to have no appreciable effect upon the calibration.

TABLE I

25-CM. SPHERES

d_1	d_2	d	E ratio kv.	f cycles per sec.	Gap cm.	$K \times 10^{-3}$	V kv.	Remarks Test No. 36
32	37	69	24.8	25	1.31	658	39.6	
32.5	36.5	69	24.8	"	1.19	"	39.6	
76.5	82	158.5	58.5	"	3.10	"	90.9	
76.5	82.5	159	58.5	"	3.10	"	90.9	
96.6	102.5	199.1	75	"	3.86	"	114	
97	102.3	199.3	75	"	4.07	"	114.3	
98.5	102.2	200.7	75	"	4.06	"	115.1	
131.5	135.5	267	100	"	5.52	"	152.8	
131.5	137	268.5	100	"	5.56	"	154	
118.5	122	240.5	90	"	4.92	"	137.8	Damping not good
106	108.5	214.2	80	"	4.38	"	122.6	brush tightened
92.5	94.5	187	70	"	3.79	"	107.2	
92.5	94	186.5	70	"	3.76	"	106.8	
60.5	60	120.5	47.3	"	2.34	"	69	
49.2	49.6	98.8	34.6	"	1.82	"	57	
								Test No. 38
42	45.5	87.5	100	25	5.71	218	151	
42.5	45.5	87.5	100	"	5.68	"	151	
53.5	57.5	111	125	"	7.29	"	191	
54	57.5	111.5	125	"	7.32	"	192	
63.5	68.5	132	150	"	9.02	"	227	
63.3	68.8	132.1	150	"	9.08	"	227	
74	79.6	153.6	176	"	11.37	"	265	
75	80	155	175	"	11.36	"	268	
85	92.5	177.5	200	"	11.17	"	306	
85	92.5	177.5	202	"	14.67	"	306	
85.5	92.5	178	200	"	14.43	"	307	
95.3	103.5	198.8	225	"	17.80	"	343	
96.2	103.6	199.8	225	"	18.02	"	345	
106.3	114	220.3	251	"	23.56	"	381	
106.2	114	220.2	251	"	24.73	"	381	Surge of voltage
106.2	113.6	219.8	249	"	23.55	"	380	
112.5	121.5	234	264	"	27.85	"	404	
102	110.5	212.5	240	25.2	21.28	"	363	
112	121	233	260	25	27.58	"	402	
105.5	115	220.5	250	"	22.79	"	381	
84.5	93	177.5	200	"	14.88	"	303	
62.3	70.1	132.4	150	25.2	9.20	"	225	
41.5	49	90.5	100	"	5.56	"	154	
41.2	49.5	90.7	100	"	5.66	"	155	

TABLE II

37½-CM. SPHERES

d_1	d_2	d	E ratio kv.	f cycles per sec.	Gap cm.	$K \times 10^{-3}$	V kv.	Remarks
								Test No. 40
25	25.2	50.4	50	25	3.04	214	87.5	
24.6	25.3	49.9	50	"	2.98	"	86.4	
41.4	41.7	83.1	100	"	5.26	"	144.1	
41.5	42.5	84	100	"	5.24	"	145.6	
61	62	123	150	"	7.96	"	215.5	
60.3	62.4	122.7	150	"	8.44	"	214.8	
70.8	73	143.8	176	"	9.61	"	249.2	
70.2	72.5	142.7	175	"	9.70	"	247.5	
81.6	83.8	165.4	201	"	11.38	"	287	
81.8	84.3	166.1	202	"	11.69	"	288	Quick rise of voltage
81.2	84	165.2	201	"	11.99	"	286.6	
91.8	95	186.8	225	"	13.35	"	323.7	
91.6	94	185.6	225	"	13.27	"	321.7	
101.5	104	205.5	250	"	15.40	"	356.3	
101	104.3	205.3	250	"	15.29	"	356	
112.5	116.5	229	275	"	18.12	"	398	
112.5	116.5	229	274	"	17.88	"	398	
118	121	239	286	"	19.18	"	415	
41.2	42.5	83.7	100	"	5.27	"	145.2	

TABLE III

50-CM. SPHERES

d_1	d_2	d	E ratio kv.	f cycles per sec.	Gap cm.	$K \times 10^{-3}$	V kv.	Remarks
								Test No. 45
28.1	26.3	54.4	61	24.75	3.45	214	96.5	
28.1	26.2	54.3	60	25	3.38	"	95	
45.3	43.6	88.9	100	25	5.68	"	155	
45.3	43.7	89	100	25	5.68	"	156	
66	64.1	130.1	150	25.25	8.66	"	226	
65.8	65.2	131	150	24.75	8.66	"	231	
88.6	88	176.6	200	25	12.23	"	308	
88.8	88.1	176.9	201	25	11.99	"	309	Frequency unsteady
88.7	88	176.7	201	25	12.17	"	308	
99.4	99	198.4	225	25.25	13.88	"	344	
99.7	99	198.7	225	25.25	13.80	"	344	
109.4	109	218.4	249	25.25	15.43	"	378	
108.8	109.2	218	249	25	15.32	"	381	Guard ring discharges through shunt
87	89.2	176.2	202	25.25	12.20	"	303	

Fig. 3, shows the calibration curves obtained for each of the three sets of spheres and tables I, II and III show the results for

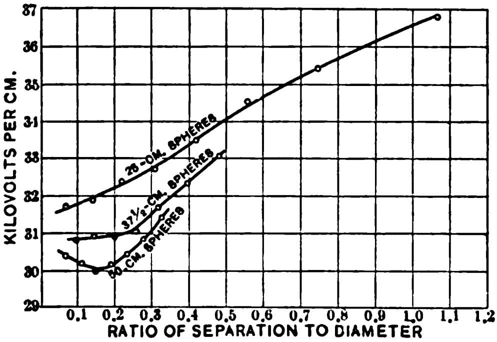

Fig. 4

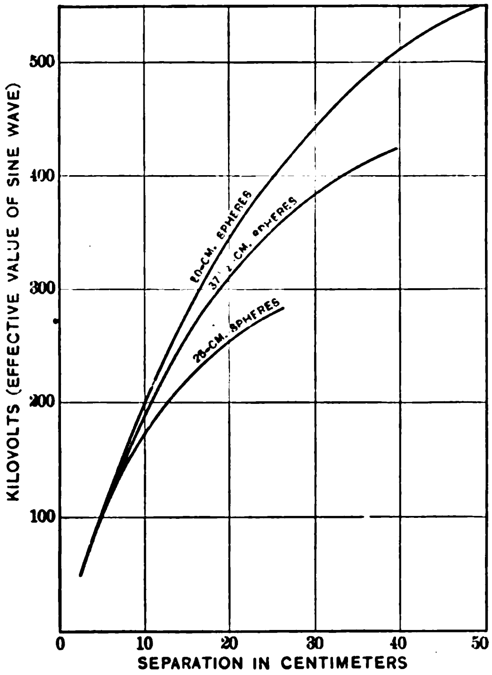

Fig. 5

a 25-cycle test of each. The curves have been drawn weighing the points of many tests. To avoid confusion only the points of the tests shown in the tables are plotted.

Fig. 4 shows the relation between surface density and the ratio of separation for the three curves of Fig. 3.

Fig. 5 shows the calibration for the three gaps extended and expressed in terms of effective values of a sine wave voltage. These curves have been derived from the curve for the 25-cm. sphere.

The authors regret that limitation of time makes it necessary to show exterpolated curves in place of direct calibration for the high voltage results. However, the curves will serve as a basis for comparison until the direct calibration can be completed.

COMMUTATION AND BRUSH LOSS

BY

C. E. WILSON

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COMMUTATION AND BRUSH LOSS

BY C. E. WILSON

Abstract of Paper

The paper discusses the brush loss in direct-current machines and calls attention to the relation between the commutating characteristics of the machines and this loss.

Examples are given of commercial brush drop tests and reasons suggested for their great variation. These tests as usually made on machines are practically worthless as a measure of the actual brush loss. Part of this loss is really a commutation loss, but there is no easy way of separating it from the brush loss proper.

The relation between the short circuit or reactance voltage, brush drop and commutation is illustrated by several examples. A machine with difficult commutating characteristics must have a high resistance brush or it will be very sensitive to sudden changes in load, brush spacing, vibration, etc.

The actual current density in parts of the brush is shown to often be two or three times the apparent density. When local currents are eliminated by using narrower brushes, resistance leads or commutating poles, higher apparent densities are permissible.

On the assumption of constant brush resistance, the brush loss is calculated and the increase in loss, due to local currents shown. Actually the increase in loss is much greater than indicated by these calculations due to the fact that the brush resistance decreases with increasing current.

At present no way of calculating or measuring the actual loss at the brushes is known. At best only a rough approximation can be obtained. Probably in a majority of cases the most satisfactory method of dealing with this loss is to obtain figures for it from brush loss tests on slip rings or short-circuited commutators. . The increase in loss actually occurring can be regarded as a commutation or load loss and as part of the stray losses of the machine.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26–28, 1913.

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Subject to final revision for the Transactions.)

COMMUTATION AND BRUSH LOSS

BY C. E. WILSON

Even when made on slip rings, or on special short-circuited commutators, brush loss tests are hard to duplicate and results of tests under similar conditions vary greatly. A number of things are known to affect the brush loss at a given current density. Among these, the most important are: The direction of current in the brushes, the glaze or polish of the collector, the surface and fit of the brushes, oil or any foreign material on the collector, the temperature of the parts and the peripheral speed of the collector.

In direct-current machines, there are still other reasons for variations in brush loss. It is likely to be increased by high mica, unequal division of current among the brushes and brush arms, vibration or chattering of the brushes, imperfect spacing of them, and, above all, by the commutation and the strength of the magnetic fields in which the short-circuited coils are commutated. In fact, tests show that one machine may have two or three times the brush drop of another of the same type, although the grade of brushes and the apparent current density in them are the same. Even in the same machine, with the same current output, the brush drop measured at the different brush arms and at different times, may vary 100 per cent or more.

Table I gives the tests on four adjustable-speed motors of the same type and at the maximum and minimum speed for which they were designed. These were chosen at random from a large number of tests made on this line of machines, all of which were equipped with the same grade of brushes.

The voltages *A*, *B* and *C* were taken at different points on the brush and commutator, as shown in Figure 1, and were measured

TABLE I

TESTED BRUSH DROPS ON ADJUSTABLE SPEED MOTORS

Rating			20 amperes per sq. in.						40 amperes per sq.in.						60 amperes per sq. in.					
H.p.	Volts	Rev. per min.	Volts *A*		Volts *B*		Volts *C*		Volts *A*		Volts *B*		Volts *C*		Volts *A*		Volts *B*		Volts *C*	
			+	—	+	—	+	—	+	—	+	—	+	—	+	—	+	—	+	—
20	115	300	1.1	0.9	0.7	0.7	0.8	0.7	1.5	1.3	1.1	0.9	1.5	1.2	2.2	1.3	1.6	1.2	2.2	1.0
		1200	1.3	1.5	0.5	0.6	-0.5	0.0	1.6	1.8	1.1	0.9	0.7	0.9	1.4	0.7	1.3	1.0	1.8	1.7
25	230	300	0.9	0.6	0.7	0.6	0.4	0.7	0.9	0.7	0.5	0.9	0.1	1.3	0.7	1.8	1.1	1.1	1.7	2.1
		1200	0.4	0.4	0.3	0.3	-0.1	-0.1	0.5	0.4	0.5	0.5	0.3	0.7	0.5	0.6	1.0	1.3	2.3	2.2
25	115	400	0.4	0.5	0.5	0.1	0.3	0.2	0.6	0.9	0.7	0.2	0.6	0.3	0.8	0.8	0.7	0.3	0.8	0.6
		1200	0.9	1.00	0.5	0.5	0.2	0.1	1.1	1.1	0.7	0.7	0.5	0.5	0.7	1.2	0.9	0.9	0.7	1.0
30	230	350	0.3	0.4	0.1	0.3	0.0	0.2	0.4	1.4	0.2	0.9	0.1	0.7	0.3	1.3	0.2	1.0	0.5	1.2
		1050	0.6	0.5	0.1	0.1	-0.6	-0.5	0.5	0.7	0.1	0.2	-0.3	-0.3	0.4	0.6	0.2	0.3	0.1	0.2

in the usual way with a low reading direct-current voltmeter and a pair of pencil points making contact at 1-1, 2-2 and 3-3, as shown. The current densities given correspond to approximately one-half, full and 50 per cent overload on the motors.

The data recorded in Table I show, principally, the extreme variations in brush drop found in commercial testing. These variations can usually be explained by one of the causes previously given. The over-shadowing influence of the commutation and the commutating field on the brush drop is also shown clearly. As far as measuring the loss is concerned, the product of the average brush drop and the load current is such a rough approximation that it is often practically worthless. In some cases the loss obtained in this way is less than the loss measured on slip rings and short-circuited commutators. It is hard to see how this can possibly be true, as all the things which affect the loss in machines tend to increase it.

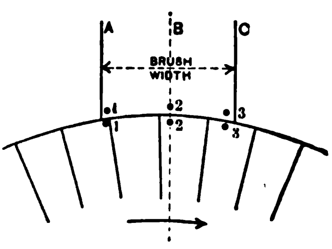

FIG. 1

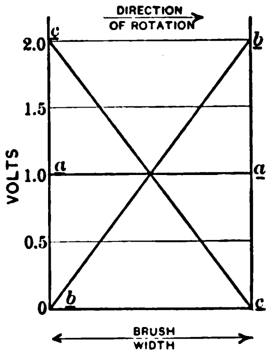

FIG. 2

It should be remembered that the primary function of a brush is to commutate and collect current. Brushes are selected for their commutating qualities, primarily, and the brush loss is of secondary importance. The commutation is first made right and then the question of loss is considered. A machine which has a high short circuit or reactance voltage demands a high resistance brush, especially in the case of a machine without compensating windings.

In the case of an ordinary commutating pole motor, a reasonable value for the total inherent short circuit voltage* across the brush at full load, is 15 volts. Assume that, in order to neutralize this voltage, the ampere turns on the commutating pole must be 30 per cent in excess of the armature ampere turns, or a total of 130 per cent. With this value of ampere turns, and with a commutating field of the proper shape, the theoretical curve *a* in Fig. 2, will be obtained. If the ampere turns on the commutating pole are decreased to 126 per cent of the armature ampere turns, the neutralizing voltage will be decreased to 13 volts and the motor will be two volts under-compensated, and a brush curve, such as *b* in Fig. 2, will be obtained. A local current will then flow in at one brush tip and out at the other. This curve assumes constant brush resistance. However, the actual curves approximate these theoretical ones with sufficient accuracy for purposes of illustration. If the ampere turns on the commutating pole should be increased to 134 per cent of the armature ampere turns, the motor will be two volts over-compensated, and curve *C* in Figure 2 will be obtained. Curves *b* and *c* show two volts drop at the trailing and leading brush tips respectively. On the assumption of constant brush resistance, this drop of two volts means double current density in the tips of the brushes. Experience shows that this drop and current density are about the maximum permissible with ordinary carbon brushes, if the machine is designed to carry a reasonable overload with perfect commutation.

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* Figured according to the method given in Mr. B. G. Lamme's paper, "A Theory of Commutation and its Application to Commutating Pole Machines", PROCEEDINGS A. I. E. E. October 1911.

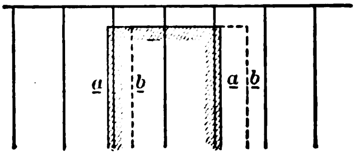

FIG. 3

To obtain this desirable adjustment in such a machine, the commutating pole ampere turns must be correct to four parts in 130, or within approximately 3 per cent. If, for any reason, the effective ampere turns on the commutating pole vary independently of the armature ampere turns in excess of 3 per cent, commutation trouble is likely to be experienced.

The voltage across the brush is usually measured with a direct-current voltmeter. If an alternating-current meter which would read correctly on high frequency were used, an entirely different reading would be obtained in the majority of cases. This is due to the variation in the short-circuit voltage which occurs during the period of commutating one bar, and in some cases, during the commutation of the bars on one slot. This variation in short-circuit or reactance voltage cannot be correctly compensated by a commutating pole which will only give the proper *average values*. It is quite apparent that a different condition is encountered when the brush is in position *a* than when in position *b* in Figure 3; likewise, when the brush passes from bar *a* to bar *b* and from bar *b* to bar *c* in Fig. 4. This is one of the reasons why the brush drop, as measured on machines, is so variable that tested values are practically meaningless and worthless as far as measuring the loss is concerned.

In the case of a non-cummutating pole machine, it is still more necessary to have a high resistance brush if the short-circuit voltage is high. It is common practice to shift the brushes of a non-cummutating pole machine from the mechanical neutral, in order to induce a voltage in the short-circuited coils, due to the main field which will neutralize the short-circuit voltage. A fair limit for the short-circuit voltage across the brush of a non-commutating pole machine at full load is six volts. Assuming high resistance carbon brushes with constant brush resistance and a drop of 1¼ volts at a nominal current density of 35 to 40 amperes per square inch (6.45 sq. cm.), the brushes may be shifted into an active field which will give five volts at no-load, and a current density in the brush tips of twice the normal value. A brush curve similar to *a* in Fig. 5 will then be obtained. At full load, this five volts will neutralize all but one volt of the short-circuit voltage and curve *b* will be obtained. At 50 per cent overload, curve *C* would be obtained with approximately three times current density in the trailing brush tip and the condition of poor commutation. The probable limit for commutation on such a machine would be 25 per cent overload. The brush loss in this machine at no-load would be considerable, and this is

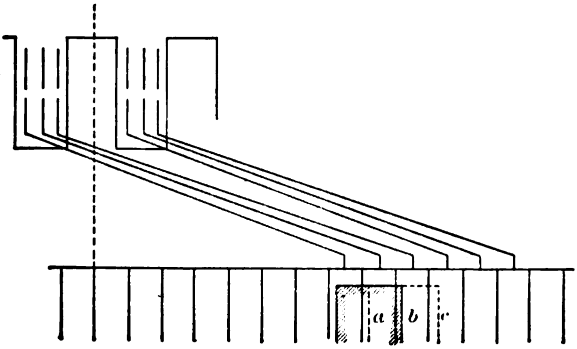

FIG. 4

often found to be the case, as shown by tests. Often the no-load losses are decreased much more by raising the brushes than can be accounted for by the decrease in loss due to the absence of brush friction. Many tests have been made to measure this no-load brush loss, and it has been found to be comparatively large. In the case of curve *c* at 50 per cent overload, Fig. 5, the loss in the tip of the brush would be approximately nine times normal, and would undoubtedly cause glowing and honey-combing of the brushes.

The commutation of non-commutating pole direct-current machines has often been improved by narrowing the brushes and increasing the apparent current density in them. For example, consider the brush in Fig. 6 to be reduced from $\frac{3}{4}$ in. (18.9 mm.) to $\frac{1}{2}$ in. (12.7 mm.). The short-circuit voltage at full load will then be approximately four volts, and curves ***a***, ***b*** and *c*, Fig. 6 will be obtained at no-load, full load and 50 per cent overload respectively. With this narrower brush the loss in the tips of the brushes is the same as before, but the total loss is less, because the section of the brush has been reduced. The loss at full load is practically the same as before, but the loss at 50 per cent overload has been reduced so that commutation might be satisfactory. Actually the improvement is greater than indicated, due to the

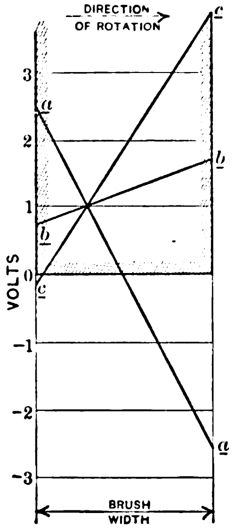

FIG. 5

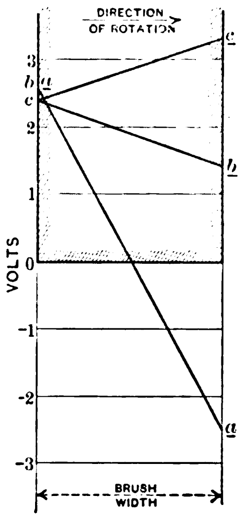

FIG. 6

fact that the brush does not have a constant resistance, but has a resistance which decreases with increase in current density.

The writer recently had this relation between brush drop and the commutating characteristics of a machine forcibly illustrated by his experience with a line of small six-volt motors. In order to improve the efficiency, very low resistance brushes were used. In a given case, the short-circuit voltage was 0.75 volt across the brush at full load. The commutation was perfect with brushes having a nominal brush drop of 0.25 to 0.3 volt at a current density given by full load on the motor. To improve the efficiency, other brushes were tried having a drop of 0.1 to 0.15 at this same current density. The efficiency by brake was practically the same for both cases, showing that the low resistance brush had not decreased the total brush loss. Also, the commutation with the second brush was poor and unsatisfactory. This same brush, having a drop of 0.1 to 0.15 volt and working at approximately the same apparent current density, gave entire satisfaction on another motor which had a short circuit voltage of only 0.35 volt across the brush at full load.

On the previous assumption of constant brush resistance, and neglecting the increase in loss due to variations in short-circuit voltage during the period of commutation, the total loss which occurs at the brush can be calculated from brush curves.

Let I_1 = Amperes per unit area.
E_1 = Brush drop at current density I.
E_2 = Short-circuit voltage across the brush.
A = Area of brushes.

Then the brush loss on a short-circuited commutator would be,

$$W = E_1 \, I_1 \, A$$

When a local current, caused by the short-circuit voltage E_2 is present in addition to the useful current, the loss can be shown to be

$$W_t = E_1 \, I_1 \, A \left(\frac{4 \, E_1^2 + \frac{1}{3} \, E_2^2}{4 \, E_1^2} \right) \text{ or if}$$

$$a = \frac{E_2}{E_1} \quad W_t = E_1 \, I_1 \, A \left(\frac{12 + a^2}{12} \right) \text{ and the increase}$$

in loss will be $8\frac{1}{3} \, a^2$ per cent.

Referring to curves *b* and *c* in Fig. 2, the increase in loss due to the local currents caused by the two volts across the brush will be 33⅓ per cent. Actually the increase in loss with such a brush curve as *b* or *c* will be considerably more than 33⅓ per cent, due to the decreasing brush resistance with increasing current, as previously mentioned. This decreasing brush resistance allows a larger local current to flow, which, of course, increases the loss.

Referring to curve *a* in Fig. 5, the brush loss at no load would be 133⅓ per cent of the loss at normal full load current density and no local currents.

There appears to be no way of measuring this increase in brush loss, or, as it may be called, commutation loss. In the average commutating pole machine, this increase in loss probably does not exceed 50 per cent, but it may be very much greater in some cases. Probably the most satisfactory method of dealing with this total brush loss is to obtain a value for what may be called the true brush loss from data obtained by tests on short-circuited commutators, and to regard any increase in loss which may occur, as commutation loss or part of the load losses.

SOURCES OF ERROR IN THE EFFICIENCY DETERMINATION OF ROTATING ELECTRIC MACHINES

BY

ELMER I. CHUTE and WILLIAM BRADSAW

Presented under the auspices of the

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SOURCES OF ERROR IN THE EFFICIENCY DETERMINATION OF ROTATING ELECTRIC MACHINES

BY ELMER I. CHUTE AND WILLIAM BRADSHAW

Abstract of Paper

This paper treats of the sources and effect of errors entering into the determination of the power efficiency of rotating electric apparatus. It is shown that where the efficiency is determined by the so-called method of " summation of separate losses " the effect of possible errors in measurement is much less than when determined by the input-output method. In the input-output method of efficiency determination all measurements enter directly into the result, so that errors in them have a maximum effect.

Attention is called to the different classes of errors likely to arise, viz., purely instrument errors, observation of reading errors, and errors due to changes in the operating condition of the machine under test. Particular stress is laid on observation errors, these probably being especially large under commercial operating conditions, due to excessive swinging of meter pointers. This swinging of meter pointers may be considerably reduced under special conditions of power supply and loading, and fairly consistent efficiencies then obtained.

It is this necessity of operating under special conditions and observing all precautions possible in the layout and conduct of an input-output test that entirely offsets its apparent simplicity.

It is next shown that, while the efficiency as determined by the loss method is not the true operating efficiency, it can be so modified by certain factors, depending upon the type of machine, as to approach very closely to that value—much closer, in fact, than the average input-output test. The probable relative accuracies are illustrated in Fig. 1.

In consideration of the equivocal results usually obtained, and in view of the laboratory methods of testing required for making accurate input-output tests, the writers do not feel that that method is to be recommended.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26-28, 1913.

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(*Subject to final revision for the Transactions.*)

SOURCES OF ERROR IN THE EFFICIENCY DETERMINATION OF ROTATING ELECTRIC MACHINES

BY ELMER I. CHUTE AND WILLIAM BRADSHAW

The efficiency of any apparatus is the ratio of its net power output to its gross power input. According to the Standardization Rules of this Institute this may be determined with certain limitations by either of two methods, by the input-output method or by the summation of separate losses.

By the first method the input and output are to be measured directly, either mechanically or electrically as the case may be; by the second the separate losses are to be determined either individually or collectively, and, in the case of generators, added to the output to give the input, or, in the case of motors, subtracted from the input to give the output. In either method the efficiency equals the output divided by the input.

To determine the loss values, measurements of resistance, core and frictional losses are involved, quite elaborate tests being usually required to determine the latter two. In the input-output test two measurements only are required, which to the uninitiated seem as though they should be obtained without any special preparation whatever, especially where both values to be measured are electrical, as will be assumed in this paper.

If all measurements could be taken with perfect accuracy there could be no discussion whatever on this subject, or even if all inaccuracies affected the final results in equal proportion, one would be as reluctant to take separate loss measurements for efficiency calculations as some are now to take input-output tests. But this is far from the case.

Inaccurate readings of power input to the driving motor, while determining the core and frictional losses, are practically the only sources of error in loss measurements. These errors, moreover, enter into the result only indirectly. In a paper* presented at the annual convention at Boston, it was shown from data on a large number of machines that even in the most extreme case when the effect is largest, an error of five per cent in the actual readings taken affects the efficiency by only one-half of one per cent. The effect in the average case is less than two tenths of one per cent. The real variation is probably much less than this, for the five per cent error assumed is a very high value seldom occurring even in commercial practise.

In the input-output test, on the other hand, all errors in measurement enter directly into the result. The five per cent above assumed (and it is as logical to assume it in one case as in the other, under equal conditions) would probably affect the efficiency at least five, if not ten per cent, depending on whether the errors in measurement of the output and input were cumulative or tended to neutralize. The probability of this may be more apparent from the following analysis of all the incorrect conditions that might exist.

Input	correct,	output	high	—	Effect	directly	proportional	to	error.
"	"	"	low	—	"	"	"	"	"
"	high	"	correct	—	"	"	"	"	"
"	low	"	"	—	"	"	"	"	"
"	high	"	low	—	"		"	to sum of error	
"	low	"	high	—	"	"	"	"	"
"	low	"	low	—	Errors	tend	to neutralize		
"	high	"	high	—	"	"	"		

It is apparent, then, that if efficiencies as consistent as those determined by the loss method are to be obtained every precaution conceivable must be taken that the observations made, or readings taken, are as little in error as possible. It is this necessity that offsets the otherwise apparent simplicity of the input-output method, and renders the test far more elaborate and costly to conduct than any other method of efficiency measurement.

A brief examination of the sources of error will bring out some of the precautions that must be observed. These may be classified as follows:

Determination of Power Efficiency of Rotating Electric Machines E. M. Olin, PROCEEDINGS, A.I.E.E., July, 1912.

a. Instrument errors.
    1. An unsuitable selection of meters or associated apparatus.
    2. Inaccuracies of calibration.
    3. Improper location or use of the instruments.
b. Observation errors.
    1. Personal errors.
    2. Errors due to fluctuation of meter indicators, depending on character of circuit.
c. Errors due to varying conditions of operation.
    1. Change in constant losses.
    2. Comparison with separate loss values not made under same conditions.

Instrument errors may be avoided to a large extent in any first class laboratory or manufacturing plant, but become of vital importance in isolated stations where suitable instruments are not available, or in plants when apparatus is much crowded or where very heavy currents are the rule.

Measuring instruments must be selected with the conditions thoroughly in view. Well damped indicating instruments have proved the best in practise. Watt-hour meters placed on both the incoming and outgoing lines would naturally seem to be the best solution of the problem, but repeated tests with the best types of available instruments have not proved as satisfactory as those taken with indicating meters.

The accurate calibration of the meters used is essential. For ordinary work the accuracy of one-half of one per cent of the full scale reading at any point on the scale, which is the usual guarantee, is sufficient, but in an input-output test even this error, considering the number of meters used, may lead to an error of two per cent or more in the efficiency of the apparatus under test. Meters if used with care can be depended on to hold this accuracy very well, but to make certain that no change in calibration has occurred during a test it is always advisable to check them at the end as well as the beginning of the test.

The proper locating of meters, especially those of the moving coil type, must be given careful consideration. They should rest on a firm, rigid support and be so located as to be free from any external field effects. It must not to be assumed that even meters of the shielded types can be exposed indiscriminately to stray fields. As a general rule the same precautions should apply to them as to others.

When one considers the large number of meters necessary on such tests, the necessity of eliminating or accounting for even the most minute errors in them is evident. In the simplest case, when the incoming and outgoing power are each direct current, four meters are necessary. In the case of synchronous converters, or motor-generators other than d-c. to d-c., the number is increased to at least seven and possibly ten, all of which enter directly into the result. In addition to the measuring instruments a number of series and potential transformers are usually required. These, however, may be very accurately calibrated provided the proper equipment is available, and can be depended on to hold their calibration well. The name-plate ratio in the case of current transformers when used at from 70 to 100 per cent of their rated load is only accurate within one-half of one per cent. Potential transformers when properly compensated may be considered accurate to three-tenths of one per cent.

Errors in reading indicating instruments vary, depending to a large extent on the variations in the circuit in which they are connected. The ideal condition, of course, is where the characteristics of the circuit permit the indicator of the meter to move at once to its proper location, and remain there as though fixed. In such cases the error is due to the inability of the average reader to locate the indicator closer than to possibly 0.1 of a division. This would introduce an error of approximately 0.13 per cent in the reading if taken at about the middle of a scale of 150 divisions. Such an error could readily be neglected if occurring in one meter only, but if such an error should exist in each of the meters used and the effect were cumulative with respect to the final result, it is evident that the error would soon be of considerable magnitude.

This ideal condition, however, may be said never to exist, the nearest approach to it being in cases where the source of power is not more than one step removed from a well regulated prime mover on which there is no variable load, and liberally designed grid resistances or a water rheostat used to absorb the power output of the apparatus under test. Under this condition the pointers of the meters will swing back and forth over a small part of the scale, perhaps only a division or two. The effort of estimaing the position of the pointer is added to the former effort to divide up the space correctly. The liability to error therefore is increased materially.

However, under the usual conditions met with in commercial work, power must be taken from generators serving many other machines, the load on which is likely to be quite variable. Loading these machines, especially the larger sizes, on water rheostats or resistances is not a desirable economical proposition. Loading-back methods, therefore, are ordinarily resorted to, so that only the losses have to be supplied from the prime mover. Under such conditions the swinging of meter pointers will be greatly increased. It not infrequently occurs that meters must be read while their indicators are wandering more or less irregularly over as much as 25 per cent of the scale. That errors of reading increase much more rapidly than the increase in length of the indicator swing is not at all improbable, though no accurate data are available as to the probable law.

If there were no compensation of errors, consistent results from data obtained under such conditions would be out of the question. It may be proved by certain laws of mathematics that the probable variation of the average of a number of readings differing widely among themselves is but little from the true but unknown value. However, the accuracy is not increased in direct proportion to the number of readings, but in proportion to their square root, so that very little is gained by taking more than ten or fifteen readings. In view of this it is customary to take readings in series of ten, a simultaneous reading being taken of all meters involved, at intervals of about ten seconds, until ten are obtained. The average of these is considered as the nearest approach to the true value. In a certain case where the maximum variation from the mean value of ten readings was 1.5 per cent, the variation, as computed from the mathematical laws previously referred to, was less than 0.2 per cent from the true, but unknown, value. This would all have been very well if the average of ten other such readings taken under as nearly as possible the same conditions had not given 1.7 per cent difference in efficiency, and according to the same laws was also accurate to within 0.2 per cent. As this is the condition that is continually arising, it is evident that even the laws of chance can give us very little help in the solution of the problem.

It would seem as though an actual change in the efficiency of the apparatus had taken place, due possibly to a change in operating conditions, or in the constant losses of the machines. But when one stops to analyze the magnitude of any such possible change one finds a considerable discrepancy still unaccounted for. However, such changes must not be ignored, especially in the case of tests on synchronous converters, where the total losses are but a very small proportion of the output of the machine. To make sure that no change of any consequence has taken place it is always well to check the frictional losses both before and after the test. This also insures that the determination of efficiency by separate losses, which is the best criterion available as to the accuracy of the input-output test, is made under identically the same conditions.

It is conceded that the efficiency by the "summation of losses" is not the true operating efficiency of the apparatus, as no account is usually taken of the so-called "load" or "stray" losses. It has been proposed to account for this discrepancy by a system of factors that depend for their magnitude on the type of apparatus. As this additional loss under load consists of additional core and copper losses, due to distorted field effects and eddy currents, it is suggested that the factor required be applied to their sum. In another paper* at present before this Institute the magnitude and determination of this constant have been discussed and its limits experimentally determined to some extent. It is interesting to compare the probabilities of error of this method with those already existing.

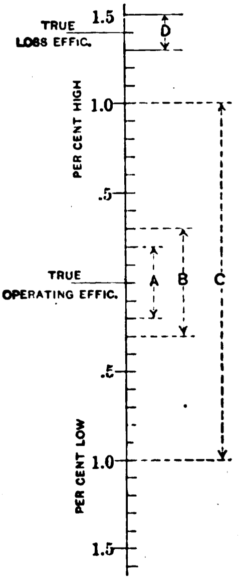

FIG. 1

Assume a concrete case of a 500-kw. direct-current generator the losses of which total 10 per cent or 50 kw., and that they are measured with an accuracy of 2 per cent. Of this 50 kw., 70 per cent., or 35 kw., will be assumed as a fair value of the sum of the core and armature copper losses. The value of the load factor for normal load, as suggested in the paper previously referred to, is about 1.3 for direct-current machines. It seems that this can be determined within ± 2 per cent or, in other words, may vary between 1.27 and 1.33.

Using the values assumed above, it will be found that the efficiency by losses at normal load will be between 91.6 and 91.8 and after applying the load factors, allowing for the above-mentioned variation, the efficiencies will be between 90 and 90.6 per cent.

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*_Determination of Load Loss Correction Factors for Rotating Electric Machines_, by E. M. Olin and S. L. Henderson; page 521 of this issue of the PROCEEDINGS.

This difference depends chiefly on the ratio of the sum of the core and the copper losses to the total loss. As this ratio decreases with the larger machines, or in those whose total losses are a small proportion of the output, the variations are reduced. The input-output test shows just the opposite tendency, for the same error is liable with small losses as with large ones and therefore becomes a much larger factor in the final efficiency.

The foregoing conditions may be represented graphically as in Fig. 1, in which *A* represents the probable limit of error in an input-output test, conducted on stable circuits and liberally designed water rheostats or grid resistances, in which all possible precautions have been taken. The limits represented by *C* cover the probable limits of error where this test is taken on commercial circuits, but where first-class testers are reading the meters and conducting the test. Under other conditions the results are entirely too variable to be represented in such a diagram. The limits covered by *B* mark the probable limit of error of efficiencies determined from losses, in connection with correcting factors, in which the correcting factors have been determined from input-output tests as conducted in the manner *A*, or from other more accurate methods whenever possible. *D* represents the possible variation in the loss efficiency.

It is apparent that input-output tests under the best conditions can be taken with a considerable degree of accuracy, but does the additional accuracy gained over the simple method suggested warrant the industry sustaining the larger additional cost of equipment and labor necessary to conduct such tests?

Efficiency values, while they should represent average operating conditions as nearly as possible, are of especial value for the comparison of the product of different manufacturers. Methods, then, that can be standardized and easily duplicated should be used in the determination of this value, so that the product of all will be on the same basis.

COMPARISON OF METHODS OF LOADING LARGE A-C. AND D-C. GENERATORS AND SYNCHRONOUS CONVERTERS FOR FACTORY TEMPERATURE TESTS

BY

F. D. NEWBURY

Presented under the auspices of the

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COMPARISON OF METHODS OF LOADING LARGE A-C. AND D-C. GENERATORS AND ROTARY CONVERTERS FOR FACTORY TEMPERATURE TESTS.

BY F. D. NEWBURY

Abstract of Paper

A satisfactory test should duplicate as completely as possible the conditions under which the machine is guranteed to operate, and the conditions of test should be more severe and not less severe than the conditions of operation.

Four methods of loading a-c. generators are described and illustrated by test results:

(a) Separate open circuit and short circuit loading is unreliable because the test conditions are radically different from operating conditions but this method may be the only possible method on account of minimum testing equipment required.

(b) Alternate open circuit and short circuit loading more nearly approaches operating conditions but results do not check with actual load unless test conditions are modified, from those theoretically determined. Experience is not, as yet, available to empirically determine proper test conditions.

(c) Direct-current open delta loading still more closely approximates operating conditions in that current and voltage are simultaneously present. The method is somewhat limited in application due to the presence of direct current in the armature. The proper field current for use in the test is shown to be that corresponding to open circuit normal voltage. The test results check well with actual operation.

(d) Zero power factor loading affords the nearest approach to actual operating conditions that has been suggested. It exactly corresponds with operating conditions except for the differences due to power factor, and these, in general, result in more severe conditions than actual loading. Test results are closer to results from actual loading than by any other method described. A direct check on field coil temperatures and exciting voltage is afforded. The application of the method is only limited by the expensive test equipment sometimes required.

The zero power factor method of loading is recommended for adoption by the Institute as the preferable method.

For d-c. generators and rotary converters, only one satisfactory method of loading has been suggested. This is the familiar loading-back method which is recommended.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26-28, 1913.

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COMPARISON OF METHODS OF LOADING LARGE A-C. AND D-C. GENERATORS AND SYNCHRONOUS CONVERTERS FOR FACTORY TEMPERATURE TESTS

BY F. D. NEWBURY

OBJECT

It is obviously impossible to test the larger machines under energy load at the factory. The advisability of making adequate tests before shipment, to eliminate as completely as possible the greater expense and delay of possible constructional changes after shipment, is generally recognized by consulting engineers and manufacturers. These facts make the question of compromise temperature tests well worth the consideration of the Insitute in connection with the work of the Standards Committee. The author believes the Standards Committee should recommend methods of loading for such factory temperature tests for the guidance of consulting engineers and others responsible for the acceptance of machines, and for the protection of manufacturers against unreasonable demands in connection with such tests. This paper has been prepared with the object of bringing before the Institute data on the relative merits of the various methods of loading which have been suggested and found practicable, and of making recommendations for its consideration.

REQUIREMENTS OF A SATISFACTORY TEST

Any adequate test should duplicate as completely as is possible the conditions under which the machine is guaranteed to operate. In addition to this obvious requirement, the factory test should be *more severe* and not *less severe* than actual operating conditions, and the test conditions of current, voltage, etc., should correspond closely with actual load conditions, so that the comparison between the two can be made directly and without the aid of experimental data.

DESCRIPTION OF METHODS OF LOADING A-C. GENERATORS

The following methods of loading have been used more or less extensively and will be considered in this paper:

a. Separate open circuit and short circuit tests.
b. Alternate open circuit and short circuit tests.
c. Direct-current open-delta test.
d. Zero power factor test.

a. *Separate Open Circuit and Short Circuit Tests.* The generator is first tested with the armature winding on open circuit and the field winding excited to give a higher armature voltage and core loss than normal in order to compensate for the absence of the armature winding loss. Then a second test is made during which the armature winding is short circuited through ammeters and the field excited sufficiently to circulate more than normal full load current. In the open-circuit test, the armature core is the only partly subjected to conditions comparable to actual load. The field winding is subjected to less than the maximum operating field current, but the temperature rise is approximately proportional to the loss, so that the temperature rise and exciting voltage can be corrected to maximum load conditions. The temperature rise of the armature winding, being on open circuit, is no guide whatever to the temperature rise under load. In the short-circuit test, the armature winding is the only partly subjected to conditions comparable to actual load. The field-winding loss and core loss are altogether too small to give rise to temperatures that would be any guide to actual load temperatures. The open-circuit test, therefore, is of value in predicting armature core and field winding temperature rises and the short circuit test is of value in predicting armature winding temperature rises.

The open-circuit and the short-circuit tests have the advantage of simplicity in manipulation and in test equipment. No equipment, other than a relatively small driving motor and measuring instruments, is required. For this reason, it is sometimes the only possible method that can be carried out under factory conditions.

The important disadvantage of this method is the difficulty of properly interpreting the results. This difficulty arises from the fact that the core loss and armature winding loss are not present in the same test, so that the combined effect of the two losses on the core and winding temperatures must be approximated from the separate test results. Experience has shown that in the large majority of machines the normal load core temperature will be lower than the open circuit core temperature when the open circuit voltage is approximately 10 per cent higher than normal, and that the normal load armature winding temperature will be lower than the short circuit test results when the short circuit current is approximately 25 per cent higher than normal.

These figures can be considered only as rough approximations. It is obvious that the combined effect of the core and copper losses on the temperature of either depends on the relative amount of the two losses, the amount and kind of insulation and the relative temperatures of the core and copper. In high-speed generators, such as steam turbine-driven generators where the core loss is normally three to four times the armature copper loss, the relation between the temperatures resulting from open circuit short-circuit tests and actual operation will be very different from that in slow speed generators where the core loss is often less than the armature copper loss. In the former class of generators, the core temperature can be predicted with reasonable accuracy from an open-circuit test alone since the smaller copper loss will have little additional effect, but in the latter case the results from both open-circuit and short-circuit tests must be given serious consideration. The insulation affects the interchange of heat between the core and coils, and for this reason the insulation must be given consideration. Usually, high-voltage machines with their greater thickness of insulation will interchange heat less readily, and a smaller increase in current than 25 per cent for the short-circuit test will give approximately the same results as actual load. The interchange of heat between coils and core will vary in direction, depending on which part has the higher temperature. At normal load, for which the coil temperature will not infrequently be lower than the core temperature, heat will flow from the core to the coils. At overloads, for which the coil temperature will generally be the higher, the flow of heat will be in the opposite direction. In machines such as turbo-generators, in which the problem of ventilation is mainly centered in the core, the flow of heat for all loads may be from the core to the coils.

While these various conditions complicate the interpretation of short-circuit and open-circuit test results, they are subject to simple laws and the existence of these conditions is not a serious objection to this method of loading, but the results from short-circuit and open-circuit tests are very considerably affected by the efficacy of the ventilation provided in the machine under test and the correction necessary for this condition cannot be easily nor infallibly applied. In general, in machines in which the core loss is larger than the copper loss the temperature of the core should be relatively low at the end of the short-circuit test. If contrary results are obtained, there is usually some fault in the ventilation of the armature core, but this is by no means a complete test for proper ventilation, and the dependence of the proper interpretation of the test results upon ventilation constitutes a serious disadvantage of this method of loading.

TABLE I

OPEN-CIRCUIT, SHORT-CIRCUIT AND ACTUAL LOAD TESTS ON 3000-KV-A. 2200-VOLT, THREE-PHASE, 60-CYCLE, 225-REV. PER MIN. WATER WHEEL GENERATORS—DEFECTIVE CORE VENTILATION

	Open circuit	Short circuit	Actual load	Actual load
Length of test in hours	7	8.5	20	12
Volts	2510	0	2280	2520
Amperes per phase	0	985	780	760
Per cent power factor	—	—	98	90.7
Field amperes	161	65.5	157	178
Field volts on rings	164	57.2		
Temperature rises:				
Stator core	32.5	30	51	53.7
Stator coils	10.5	30	27	20.7
Rotor coils	34.5	12.5	35	46.7
Air temperature	20.5	18	26	39.8

Field coil resistance at 25 deg. cent. = 0.818 ohms.
Armature coil resistance per phase 25 deg. cent. = 0.016 ohms.
Core loss at 2200 volts = 48 kw.
Core loss at 2510 volts = 63 kw.

In Tables I and II, results from short-circuit and open-circuit temperature tests and tests under actual energy load are given which illustrate the discrepancies which may occur due to defective ventilation. In these 3000-kv-a. generators, it will be noted that the temperature rise in the core on open circuit was 32.5 deg., and the short-circuit test showed a temperature rise of 30 deg. in both armature winding and core. The tests under normal load showed a temperature rise considerably above the open circuit core temperature and an armature coil temperature somewhat below the short circuit temperature rise. The excessive core temperature was found on investigation to be due to insufficient armature core ventilation and the results after this defect was corrected (Table II) showed substantial agreement between the results of the open-circuit short-circuit tests and actual energy load. The discrepancy between the core temperatures in the compromise test and in the actual load tests can be explained only on the assumption that on open circuit the low temperature of the armature winding caused a large part of the heat generated in the core to be conducted from the core to the external air through the armature coils, thereby maintaining the core at a fairly low temperature. During the load tests, the temperature of the copper in the slots was probably not materially different from that of the core so that this avenue of escape for the core heat was shut off, resulting in high core temperature.

TABLE II

OPEN-CIRCUIT, SHORT-CIRCUIT AND ACTUAL LOAD TESTS ON SAME GENERATOR AS IN TABLE I AFTER VENTILATION WAS CORRECTED

	Open circuit	Short circuit	Actual load	D-c. open delta	
Length of test hours........	7.5	10.5	10	8.5	11
Volts......................	2520	0	2460	2200	2540
Amperes per phase.........	0	788	795	788	988
Per cent power factor.......	—	—	88.5	—	—
Field amperes..............	159	51.5	181	137	161
Field volts on rings.........	147.5	44	162	127.5	152
Temperature rises:					
Stator core...........	27	15.5	33.6	26.8	37.8
Stator coils...........	16	15.5	17.1	14.8	20.8
Rotor coils...........	28.5	6.5	33.1	19.3	25.8
Air temperatures......	18	20	33	17.2	17.2

The difference in actual temperature conditions on open circuit and under a compromise load which experience has shown to approximate actual load, is shown in Table III. These results were obtained by indications from thermocouples located in the center of the slots of a 3800-kv-a., 4000-volt, 60-cycle three-phase 400 rev. per min. generator. These results show the great influence of the core losses on the coil temperatures, or, in other words, the important part the coils play in conducting heat from the interior of the core to the outer cooling air, particularly when the loss generated within the coils is negligible. The true conditions are entirely masked by the usual thermometer readings.

A minor disadvantage of the short-circuit and open-circuit method of test is the inability to adequately test the field winding for temperature and exciting voltage margin. The field current used in the open-circuit test is approximately equal to the full load 100 per cent power factor field current. To test with a field current even approaching that required for the maximum load and low power factor for which the generator is usually designed would result in a prohibitive core loss and temperature. With this method of testing, the guarantees involving the field winding must be checked by calculation from the relatively low field current used in the test. This disadvantage applies not only to the field coil temperature but to the exciting voltage. It is of considerable advantage in a compromise test that the field excitation required should be a maximum. In that event, the exciting voltage shown by the test record will directly indicate the adequacy or inadequacy of the design in this respect.

TABLE III

OPEN-CIRCUIT AND ZERO POWER FACTOR TESTS WITH THERMO-COUPLE READINGS OF TEMPERATURE

	Open circuit 4000 volts 0 amperes	0 Per cent power factor 4000 volts 550 amp.	Open circuit 4800 volts 0 amperes	0 Per cent power factor 4800 volts 550 amp.
Core—tooth 1/2 in. below air gap......	36	45	55.5	66
Core—1/2 in. below slot...............	35	44	53.5	62
Core—1/2 in. inside outer surface of core	32	38	48.5	55
Core—outer surface (by thermometer)..	23	31	44	47
Max armature coil temperature in center of core..........................	28.5	40	45	60
Max. armature coil temperature on ends of coils by thermometer.............	7	17	18	26.5

b. *Alternate Open Circuit and Short Circuit Tests.* As has been pointed out, the difficulty in properly interpreting the results from the separate short-circuit and open-circuit tests would be eliminated if both core and copper losses were present in the same test as in actual operation. To more closely approximate this condition, it has been suggested to test the generator under a succession of short cycles, each cycle consisting of a short-circuit and open-circuit test. The values of current and voltage during the short-circuit and open-circuit parts of the cycle are determined so that the average core loss during the cycle and the average copper loss during the cycle are equal respectively to the core loss and copper loss during actual load conditions. The average loss during the complete cycle and the loss during normal operation will be equal, and if the length of the cycle is sufficiently short the temperatures should be the same under the test conditions and actual load. The division of time between the open circuit and short circuit parts of the cycle may be arbitrarily made within fairly wide limits. If the lengths of time are very different, either core loss or copper loss will have to be abnormally increased to maintain the desired average so it will be found desirable to divide the cycle into approximately equal parts. If the two losses are sufficiently near together in value, it is of advantage, theoretically at least, to divide the cycle between the two conditions in the ratio of each loss to the total losses. With the time so divided, not only will the average losses during a complete cycle equal the normal load losses during an equal time but the core loss during the open circuit and the copper loss during the short circuit part of the cycle will equal the sum of the core loss and copper loss during normal operation.

Since this test has only recently been suggested and is probably not as familiar as the other tests discussed, an example will be described in detail. The test described was made on a 6250-kv-a. 6600-volt three-phase 60-cycle 240-rev. per min. water wheel generator. The core and copper losses under actual load were approximated from separate loss measurements by taking the core loss from the open-circuit core-loss curve at the total induced voltage under normal load and normal voltage and the armature copper loss was taken for normal current from the short-circuit loss curve. This latter loss is greater than that actually existing under load since it includes not only the copper loss but the core loss, and to this extent is an unfavorable assumption. The corresponding favorable assumption would be the use of $I^2 R$ loss only. The numerical values for this generator are as follows:

Losses as determined from separate loss test.

At 6640 volts (total induced) core loss =	93 kw.
At 547 amperes short circuit kw. loss =	72 kw.
Total losses at normal load,	165 kw.

165 kw. open-circuit core-loss is obtained at 8200 volts and 280 field amperes.

165 kw. short-circuit loss is obtained at 875 armature amperes and 125 field amperes.

Dividing the time proportionally to the losses:

$$\text{Time on core loss} = \frac{93}{165} = 56 \text{ per cent.}$$

$$\text{Time on copper loss} = \frac{72}{165} = 44 \text{ per cent.}$$

Choosing a 30-minute cycle, the time on open circuit would be 17 minutes and the time on short circuit would be 13 minutes.

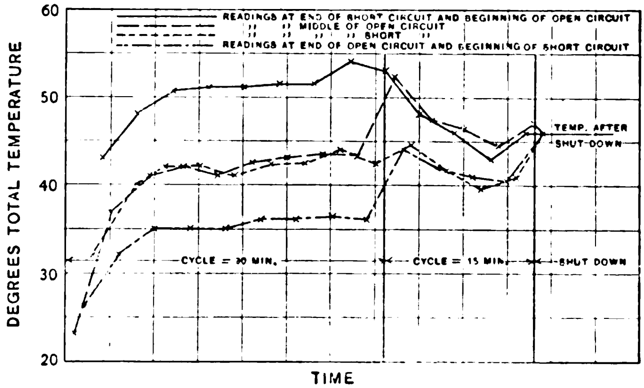

FIG. 1—ALTERNATE OPEN-CIRCUIT AND SHORT-CIRCUIT LOADING—TYPICAL ARMATURE COPPER TEMPERATURES

The value of the field copper loss in kw-hours will be dependent upon the values of open-circuit voltage and short-circuit current assumed. This loss must be compared with the loss under operating conditions and the results interpreted accordingly. In this example, the figures are:

$$\begin{aligned} \text{Field loss per hour} &= 280^2 \times 0.6 \times 0.56 = 26.5 \\ & 125^2 \times 0.6 \times 0.44 = \underline{4.15} \\ & 30.65 \end{aligned}$$

The field loss per hour under normal load 100 per cent power factor is 19-kw., and at normal load zero power factor is 46.5 kw. Thermometer readings were made at the middle and end of each part of the cycle in order to follow the temperature changes. On a generator of this size, it is not desirable to change from open circuit to short circuit with the full excitation used in the test. The field current was, therefore, reduced to practically zero and brought up again to the short-circuit value in changing from the open-circuit to the short-circuit condition. Typical core and copper temperature logs are shown in the curves, Figs. 1 and 2, and the final temperature results are shown in Table IV.

It will be noted from these results that while the armature and field copper temperatures check fairly well with the results from other methods of loading, the core temperature is much too high.

Results from a similar test on a 150-kv-a., 2400-volt., 60-cycle 900-rev. per min. belted generator tested under conditions to correspond to its normal rating of 150 kv-a., and also under conditions corresponding to 200 kv-a., are shown in Table V.

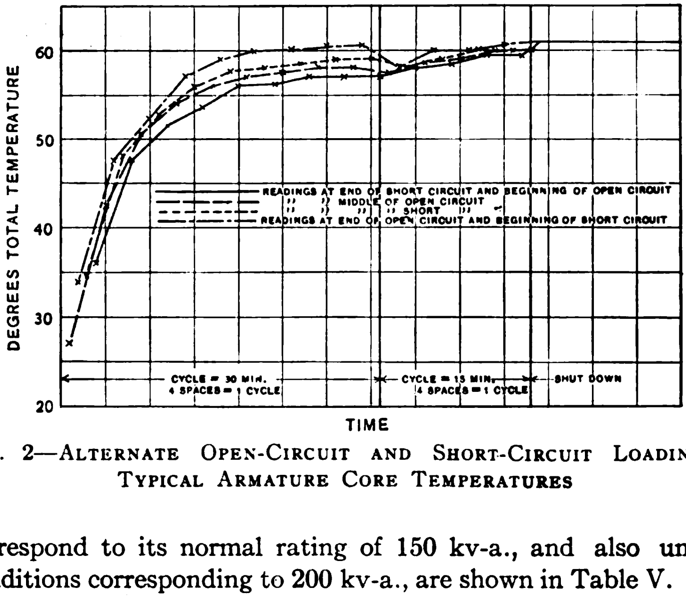

FIG. 2—ALTERNATE OPEN-CIRCUIT AND SHORT-CIRCUIT LOADING—TYPICAL ARMATURE CORE TEMPERATURES

It will be noted that the results from these cycle tests correspond fairly well with actual load and with zero power factor tests except in the field copper temperatures.

The temperature logs, Figs. 1 and 2, show.

1. The variation in temperature is much greater in the armature copper than in the armature core, due to the smaller volume of the former and the consequent greater concentration of loss.

2. The longer the cycle the greater this variation. A fifteen minute cycle appears to be a sufficiently short cycle for a large generator such as the one described.

The high core temperature obtained in comparison with the core temperatures obtained by other methods of loading indicates that the losses on open circuit should be reduced possibly to the value found by experience to be correct for the separate open circuit test. This is the core loss for 110 per cent normal voltage instead of 124 per cent normal voltage as used in the alternate open-circuit, short-circuit test described. But any such departure from a logical and simple basis to an empirical basis is a decided disadvantage in a standard method of test. While the correct core loss for the test of this generator could be found by comparative tests, the relation so found might or might not apply to another generator of different proportions, depending on all of the factors influencing the transmission of heat between the core and winding.

TABLE IV

ALTERNATE OPEN-CIRCUIT AND SHORT-CIRCUIT TEST AND COMPARATIVE DIRECT-CURRENT, OPEN-DELTA AND ZERO PER CENT POWER FACTOR TESTS ON 6250 KV-A., 6600-VOLT, THREE-PHASE, 60 CYCLE, 240-REV. PER MIN. GENERATOR

All tests continued until constant temperatures attained.

	D-C. delta	0 per cent power factor	Cycle
Volts	6600	6600	0/8200
Amperes per phase	547	547	0/867
Per cent power factor		0	
Field amperes	159	278	127/305
Field volts	90.5	174.5	160/380
Rise stator core	33.4	32.5	41.5
Stator copper thermometer	26.4	26.5	30.5
Rotor copper thermometer	17.4	40	33.5
Rotor core	17	14	33
Air temp. room	20.6	22.5	19.5

c. *Direct-current Open-delta Test.* This method of loading is still closer to the conditions existing under normal operation in that the generator is excited to correspond to normal voltage and the armature winding simultaneously carries current corresponding to normal load. The winding, if not already so connected, is connected in delta in the case of three-phase winding or in the equivalent closed winding in the case of two-phase windings, and one corner of the closed winding is opened and direct current is introduced and circulated through the complete winding. Since the alternating voltage is balanced at any corner of the closed winding, no alternating voltage is introduced in the direct current circuit and a direct voltage equal to the resistance drop to the alternating current winding is all that is required. The presence of the direct current in the armature winding results in a stationary field with respect to the armature having a pole for each phase of each pole of the a-c. generator. With chorded armature windings, the value of this field is reduced until with a three-phase winding having a throw equal to two-thirds of the pitch this direct current field disappears. These statements can be easily checked by plotting the field form due to the distributed armature winding in the same manner as the field form of induction motors is commonly plotted. Since this direct current field is stationary with respect to the armature, it generates voltages in any solid part of the field magnets, and since it has three times the number of poles as the generator the losses due to the stationary field may be considerable if there is any considerable volume of solid metal in the field. In a 3000-kv-a., 225-rev. per. min. 60-cycle generator having laminated poles and solid end plates and with non-magnetic wedges between poles to retain the field coils this additional loss in the rotating field

TABLE V

COMPARATIVE TESTS ON 150 KV-A., 2400-VOLT, THREE-PHASE, 60-CYCLE, 900 REV. PER MIN. GENERATOR

All tests continued until constant temperatures attained.

	Actual load	Zero power factor	Cycle 1	Actual load	Zero power factor	Cycle 2
Volts	2400	2400	0/	2400	2400	0/3150
Amperes per phase	36.1	39.5	0/60.3	48	48.2	0/63
Per cent power factor	100	0		100	0	
Field amperes	17.3	25.7	14/53	19.4	28	15.8/31
Field volts	62.5	102.8	20/77	72	119.5	63/127
Rise stator core	24.5	24.5	23	27	30.5	31
Stator cop. thermometer	19.5	15.5	16	23.5	28	21
Rotor cop. thermometer	23	45	24	26	64	49.5
Rotor core	13.5	15.5	13	20	25	17.5
Air temperature room	23.5	19	25	24.5	20	24.5

Cycle (1) Open circuit, 14 minutes.
Short circuit, 6 minutes.
Cycle during last hour of test reduced to 5 minutes.

Cycle (2) Open circuit, 16 minutes.
Short circuit, 14 minutes.
Cycle during last hour of test reduced to 15 minutes.

magnets amounted to 7.6 kw. In a larger generator of similar construction, this loss amounted to 17 kw. Losses of this magnitude may easily increase the temperature rise of the field coils and so vitiate the test results. This method of test is, therefore, limited to generators in which the magnet poles are mainly laminated unless the armature winding is considerably chorded. In any event, the additional power required to drive the generator under test should be observed, with and without the circulating direct current, in order to check the additional losses due to it before reliance is placed upon test results.

The correct field current to use with this method of loading is very little more than the field current to give normal voltage on open circuit, and no appreciable error is introduced by the use of open circuit normal voltage field current. Obviously, the excitation should be such as to duplicate full load core loss as nearly as this can be duplicated without alternating current in the armature winding. This condition will be attained when the excitation is sufficient to produce the flux required for the induced voltage with normal terminal voltage and normal armature current. This flux is equal to the flux required to produce an open circuit voltage equal to the vector sum of terminal voltage, and voltage drop due to armature resistance and the voltage drop due to self-induction of that part of the armature winding *outside of the core*. The larger field current actually required by load conditions (accounted for mainly by armature demagnetization) is neutralized by the armature load current and does not result in increased armature flux. That this value of field current is substantially correct is shown by numerous cases where the results of this method of loading have been compared with

TABLE VI

COMPARATIVE TEMPERATURE RISES—LEADING AND LAGGING 60 PER CENT POWER FACTOR TESTS

	Lagging	Leading
Length of test in hours	11.5	11.5
Volts	6300	6300
Amperes per phase	344	344
Per cent power factor	60	60
Field amperes	135	48
Field volts on rings	102.5	35
Rise stator core	27.5	27
Stator copper thermometer	14.5	14
Rotor copper thermometer	14	5.5
Air temperature room	21	21.5

the results from zero power factor method and from acutal energy load.

A further check on this same point is afforded by the comparison of test results made at zero power factor or at higher power factors leading and lagging. Such comparative results are shown in Tables VI and VII for a 2250-kw. 3750-kv-a., 6300-volt three-phase 50-cycle 300-rev. per min. synchronous motor operating at 60 per cent power factor leading and lagging and a 6000-kv-a., generator operating at zero power factor leading and lagging.

It will be noted that in both cases the core temperatures are practically the same at the leading and lagging power factors which indicates very little difference between actual load flux corresponding to the true induced voltage. The reason armature self-induction due to that part of the winding in the slots is not included is that this part of the self-induction, like the armature reaction, does not result in an increased flux and generated voltage but merely produces a flux which must be neutralized by the main flux. A further reason why differences in loading do not produce differences in temperature rise, as commonly measured, is that the differences in loss produced by loading occur mainly in the armature teeth where accurate thermometer temperature measurements cannot be made.

TABLE VII

COMPARATIVE LEADING AND LAGGING ZERO POWER FACTOR TESTS
6000-KV-A., 400 REV. PER MIN. GENERATOR

Generator operated at normal load until constant temperatures attained, followed by 25 per cent overload for three hours

	Lagging	Leading
Volts	4000	4000
Amperes per phase	1083	1083
Per cent power factor	0	0
Field amperes	177	2
Field volts on rings	222	—
Rise stator core	40.5	40.5
Stator copper thermometer	41	37
Rotor copper thermometer	28.5	6
Air temperature room	24.5	22

Special armature windings having only one coil per slot may introduce irregular direct-current wave forms which will have an effect on the field-core heating and temperature. Whether this is a serious matter can always be determined by plotting the field form or checking the losses due to the direct current.

To summarize, the test conditions of this method of loading are the same as those existing under actual load except for the lower field winding loss and for whatever difference results from the use of direct current in the armature winding instead of alternating current. In general, the core temperatures will correspond very closely with those obtained from actual operation. The armature copper temperature will be slightly less than that obtained from actual operation and the field coil temperature and exciting voltage will be considerably less than that obtained from actual operation. The differences in field coil temperature and excitation are not a serious objection to the method of test since both can be corrected to any desired condition of operation by proportional calculation.

d. *Zero Power Factor Method of Loading.* With this method of loading, the generator under test is operated in parallel with a generator of the same voltage and frequency and of, at least, equal current capacity. The generator under test is over-excited and the generator in parallel with it under-excited until the desired armature current flows. The generator under test, therefore, is operating under normal voltage, normal current and a field current equal to or greater than the maximum value ever required under operating conditions. The test is, therefore, made under more severe conditions than actual full load at any operating power factor.

TABLE VIII
COMPARATIVE TESTS ON 12,500-KV-A., 6600-VOLT, THREE-PHASE, 50-CYCLE, 300 REV. PER MIN. VERTICAL SHAFT GENERATOR

	Zero power factor	D-C. delta
Volts	6600	6700
Amperes	877	877
Per cent power factor	0	—
Field amperes	281	170
Rise stator core	35.5	36
Stator copper thermometer	35	29.5
Rotor copper thermometer	37.5	17

The one limitation in the application of this method of loading is the necessity for testing equipment equal in kilovolt-ampere capacity to the generator under test. When there are two duplicate generators being built, this limitation obviously does not apply since one generator can be tested in parallel with the other. This duplicate generator will not always be available and in some cases, and even when it is, the expense for a duplicate test rig may be prohibitive. This is generally the case with large vertical generators where the thrust bearing is supplied as part of the water wheel. A large number of comparative tests made at zero power factor and under actual load conditions shows the substantial agreement between the zero power factor and actual loading.

Various tests from which comparisons between actual load, the direct-current circulating method of loading and the zero power factor method of loading can be compared are given in Tables VIII, IX and X. Comparative results from d-c. open delta and actual load tests are also given in Table II. From Table VIII, it will be noted in the direct current circulating test the field excitation was slightly above that required for open circuit normal voltage and the core temperature was slightly above that obtained on the zero power factor test. This bears out the statement made in connection with the proper value of field current

TABLE IX

COMPARATIVE TESTS ON 5000-KV-A., 6600-VOLT, THREE-PHASE, 50-CYCLE, 300 REV. PER MIN. GENERATORS

	Actual load	D-C. delta	Actual load	D-C. delta
Volts	6000	6000	5910	6000
Amperes per phase	480	480	600	600
Per cent. power factor	100		100	
Field amperes	128.5	118	136	118
Field volts on rings	145	125	155	125
Rise stator core	34	35	43	42
Stator copper thermometer	30	25	46	40
Rotor copper thermometer	26	25.5	27	29

TABLE X

COMPARATIVE TESTS ON 1400-KV-A., 2300-VOLT, THREE-PHASE, 60-CYCLE, 200 REV. PER MIN. GENERATORS

	Open circuit	Short circuit	D-C delta	0 per cent power factor
Volts	2550	0	2300	2300
Amperes per phase	0	440	352	352
Per cent power factor				0
Field amperes	106.5	53	97	139
Rise stator core	20.5	10	22	24.5
Stator copper thermometer	9	7	14.5	17
Rotor copper thermometer	10	3	8	16.5

in the direct current circulating test. It will also be noted that the armature winding temperature rise is somewhat lower on the direct current test than on the zero power factor test.

CONCLUSIONS

Of the four methods of loading discussed, it is the author's opinion that the zero power factor method more nearly approaches the requirements of a satisfactory method of loading, as outlined in the early part of this paper. The conditions in this method of loading correspond almost exactly with conditions of actual operation so that no question can arise as to the proper voltage, armature current and field current to use in the test, and whatever differences exist make the test more severe and not less severe than actual load. The tests also gives a direct indication of the field coil temperature and exciting voltage under maximum conditions of operation. If, on account of lack of equipment, this method of loading is not feasible, the author recommends that the direct-current circulating test and the separate short-circuit and open-circuit method be substituted in the order given. The alternate short-circuit and open-circuit test is not recommended on account of the wide divergence from actual operating conditions, making the question of correspondence between the conditions of test and conditions of operation entirely one of judgment and experience in which the two parties concerned may not agree. However, as experience with this method of loading is accumulated, it may prove preferable to the separate open-circuits and short-circuit methods as it does more nearly approach actual operating conditions than the separate tests.

METHODS OF LOADING LARGE D-C. GENERATORS AND SYNCHRONOUS CONVERTERS

There has been only one method of loading suggested or used which gives results of any value in comparison with the results from actual operation. This method is the well-known " loading back " method in which two machines of equal capacity are operated together, one as a generator and the other as a motor. The correspondence with actual operating conditions is exact as fas as commutation and temperature on steady load are concerned. Where a second machine is not available, the field coil temperature can be checked by an open-circuit test. The core and copper temperatures on such a test are of very little value on account of the absence of the relatively large armature copper loss. The commutation, however, can be checked by operating at zero voltage or reduced voltage and normal current providing the generator is provided with commutating poles. Such tests are advisable but do not afford any adequate test of temperatures.

It is recommended that the loading-back method of test be used for d-c. generators and rotary converters when the necessary apparatus is available at the factory and the generator is too large to test on a resistance load.

THE DETERMINATION OF STRAY LOSSES FROM INPUT-OUTPUT TESTS

BY

L. T. ROBINSON

Presented under the auspices of the

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THE DETERMINATION OF STRAY LOSSES FROM INPUT-OUTPUT TESTS

BY L. T. ROBINSON

Abstract of Paper

The paper discusses the precision that can be expected in determining efficiency of certain types of direct-connected sets by careful input-output tests.

The method of dealing with the results obtained is given in some detail and the conclusion is reached that such efficiency tests can be made to within about 1 part in 500.

This degree of precision is closer than the limits within which the efficiency can be relied upon to remain constant.

The efficiency is sometimes indefinite to as much as the general order of ½ per cent, because the no-load losses do not remain constant.

Stray losses determined from input-output tests may therefore vary considerably more than the efficiency measures, but large stray losses can be detected with certainty and the small losses usually found can be found with sufficient degree of exactness to serve as a reliable check on other and more suitable direct methods.

Without such check, direct methods are usually not quite conclusive, because of failure to include all possible sources of loss or to realize completely operating conditions during tests.

Accurate input-output tests under commercial conditions require too much time and involve too much labor to allow of their regular use for general testing, although they are useful as a basis of final reference.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26-28, 1913.

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(*Subject to final revision for the Transactions.*)

THE DETERMINATION OF STRAY LOSSES FROM INPUT-OUTPUT TESTS

BY L. T. ROBINSON

It is usual in ordinary testing, even after exercising considerable care, to get results not better than the general order of one per cent.

The purpose of the present paper is to show that input-output tests can be made, using commercial measuring instruments and under shop conditions, that will give, if extreme care is taken throughout, efficiency values within one part in 500, and that with such results, a general idea of the stray losses may be obtained within about 0.2 of one per cent of the full load output.

With this degree of precision, the stray loss curve expressed as per cent of full load output, and plotted against the output of the machine, can be shown as a curved belt, 0.4 per cent wide, thus giving the stray losses definitely to a varying degree of approximation depending on the amount of such loss.

In computing stray losses from efficiency tests by input-output method, the fact that some of the points obtained do not lie within the prescribed belt is felt to be due more to the fact that certain components of the losses which are determined under no-load are variable than to any failure of the efficiency determinations to come within the prescribed limits. For example, in one instance, Curve 3, Table XIV, the brush and bearing friction alone would, if varied about 25 per cent in the right direction, reduce the stray losses to zero, and it is felt that some such effect caused the losses on 100 and 125 per cent load on this set to fall below what would ordinarily be expected.

If this point had been more fully appreciated during the progress of the tests certain components of the no-load losses that enter largely into the final results would have been determined at frequent intervals during the tests instead of once for all before the efficiency runs. Careful examination of the final tests shows that the difficulty is not so much to be found in obtaining a trustworthy measure of the efficiency as in obtaining the true stray losses, by substracting from the definitely known total losses, under load, the somewhat indefinitely known no-load components corresponding to each full load determination.

In the examples chosen, the stray losses do not exceed the general order of 1 per cent of the full load output, and hence the stray losses, assuming that the no-load losses remain constant, may be definitely known within 20 per cent. Obviously, the approximation will be 10 per cent if the stray losses are 2 per cent of full load output, and 40 per cent if the stray losses are $\frac{1}{2}$ per cent of full load output.

The accuracy obtainable in this way is, of course, decidedly inferior to that obtainable if the losses could be obtained by direct measurement, using only ordinary care in obtaining the results. However, direct methods are not always known for determining stray loss which may be applied to any and all types and sizes of machines to which input-output testing is applicable, and the development and acceptance of any such methods must depend, in the final analysis, on some over-all efficiency measurement by input-output tests or by similar means.

If it has been shown that the attainable precision is of the general order of 1 in 500, the presumption is that directly determined stray losses falling within the belt would represent more definitely the magnitude of the losses sought, than the center of the belt, and also more correctly the change in such losses with change of load. On the other hand, it is always possible to omit from consideration some conditions of testing when stray losses are directly determined, and determination of over-all efficiency within 0.2 per cent precludes the possibility of large stray losses or any that would be of interest to the user from being overlooked.

Besides the degree of precision possible in obtaining the efficiency in terms of the test instruments employed, must be considered the calibration and testing of the instruments used, so that the input and output may be known in the same terms.

In all the cases considered the input was alternating current, and the voltage and current components were of such magnitude that current and pressure transformers were required in the measurements. The output was direct current.

In estimating the permissible average deviation in results the following were considered:

1. Determination of input and output in terms of the instrument employed.
2. Precision of wattmeters used for input.
3. Precision of instrument transformers used.
4. Resistance of shunts used for output in connection with millivoltmeters.
5. Precision of millivoltmeters used with shunts for measuring output current.
6. Voltmeters for measuring pressure of d-c. output.

No attempt will be made to give in conventional style a complete discussion of the probable error in relation to the six things involved, or to establish the correctness of the conclusions reached, except by reference to the tabulated results or to the curves which follow. The contention is that the results obtained usually indicate that the precision estimated is more often attained than not. All the points determined from averages are given, and enough of them lie outside the estimated belt to indicate, as would be expected, that not every point will fall within the probable region.

Taking up the various headings in order:

1. The efficiency, or ratio of instrument readings, output divided by input, was determined in connection with each complete observation, and the deviation of each efficiency or ratio so computed from the average, was used as a basis for determining the average deviation as follows:

$$\text{Average deviation of mean} = \frac{\Sigma d_1 \ldots d_n}{R\,n\sqrt{n}}$$

where $d_1 \ldots$, and $d_n \ldots$, are the individual variations from the average ratio, n is the number of observations taken and R is the ratio of input to output. The number of observations is increased until the average deviation is about 0.15 per cent.

In determining average deviation of mean it is preferable to follow the procedure of Tables V to XV and use the ratio of input reading to output reading, rather than to complete each separate efficiency. The labor is much less and the opportunity is entirely removed to unconciously be influenced by preconceived notions of what efficiency may be expected.

2. Wattmeters were checked by comparison with usual standards at several points very close to the respective values to be

determined, and these checks were compared carefully with previous similar sets of observations to determine with greater accuracy the true values to be used. The average deviation of these values at any point did not exceed 0.07 per cent.

3. Instrument transformers used were checked by potentiometer methods of comparison giving average deviation of 0.05 per cent for current and the same for pressure transformers.

4. Resistance of shunts used for measuring the d-c. output was not considered in connection with the precision estimates. It is possible, either by a single determination using a great deal of care, or by averaging a number of independent determinations, to know the resistance of these shunts within limits so small that they would not appreciably affect the accuracy of the results.

5. Millivoltmeters used on these shunts for measuring d-c. were felt to be somewhat more capable of accurate comparison with standards than the wattmeters, therefore the value 0.05 per cent was taken.

6. Voltmeter errors were estimated to be the same as millivoltmeter, 0.05 per cent.

Effects of temperature variation were eliminated by carrying out all the tests to completion when the series was started, and disturbing influences of surrounding machinery and circuits were very carefully guarded against. In addition to this, shielded instruments were used in every instance.

In must be borne in mind quite clearly that no attempt is being made to state that instruments can be ordinarily relied upon, based on the usual single comparison, to within anything like the accuracies here estimated. It is usual to take only one reading at a point, instead of a closely bunched set of three or five readings, and to neglect entirely previous comparisons at the same point made on the instrument. The average deviation in connection with all the items referred to was handled in the same way as that given under (1).

For a final precision measure we get

$$\sqrt{0.15^2 + 0.07^2 + 0.05^2 + 0.05^2 + 0.05^2 + 0.05^2} = 0.19 \text{ per cent}$$

or roughly, as previously stated, 0.2 per cent. The only significance that was attached to this very elementary computation, was to draw from it the conclusion that, by using very unusual care in all the work, the desired degree of precision could be obtained, and it is believed that the results amply justify this conclusion. This estimate refers to efficiency alone and, for reasons previously given, cannot be extended, in all cases, to cover the stray loss determinations as well.

It is usually customary to translate values obtained in a manner similar to those referred to above into "probable error" by multiplying by about two-thirds, but this was not done, in order to be on the safe side.

CONCLUSIONS

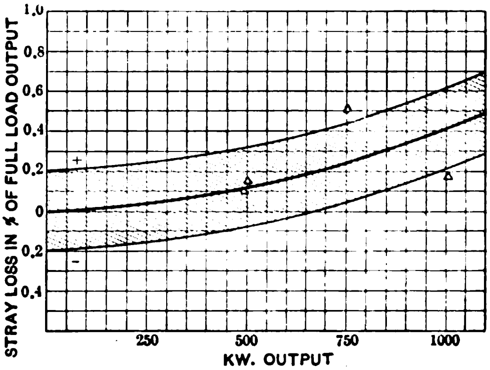
Tests like the following, resulting in efficiency determination within 0.2 per cent, may be successfully made with commercial instruments and on commercial circuits by using unusual care and with a considerable expenditure of time in arranging the tests and taking the observations. The labor of tabulating and computing the results, together with the labor in connection with the checking of instruments and accessories, is far more than the labor of obtaining the observations or setting up the tests.

In the checking of the instruments and computing the test results a high order of skill and reliability is demanded, such as can be obtained only by training average operators to do the work with the necessary degree of care by keeping them continuously employed at it for some time, or as an alternative, utilizing several high priced men computing and arranging for such tests. In either case the cost of the work, if it is done well enough to be of value, will be so great that it is not permissible except in connection with large sets of comparatively high cost and as a check method for demonstrating the reliability of other methods better suited to commercial needs. The method, is, therefore, clearly one that can be considered only in connection with special investigations.

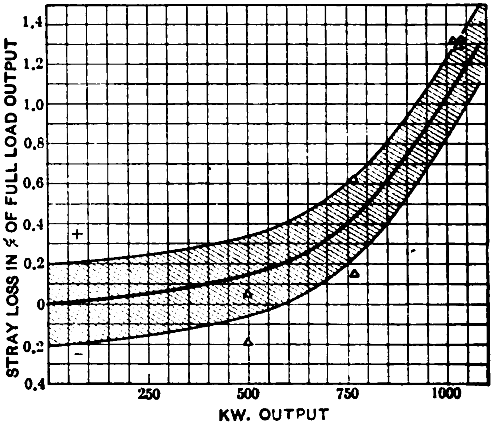
The test observers need not be especially skilled if computation of deviations from average are carried on simultaneously with the test and the number of separate observations increased until the desired precision limits are obtained. Such unskilled observers may increase the number of readings necessary from 9 or 10 per point to three or four times that number, or even more, with the corresponding increase in labor of computing, etc.

The same effect may occur with unsteady current supply.

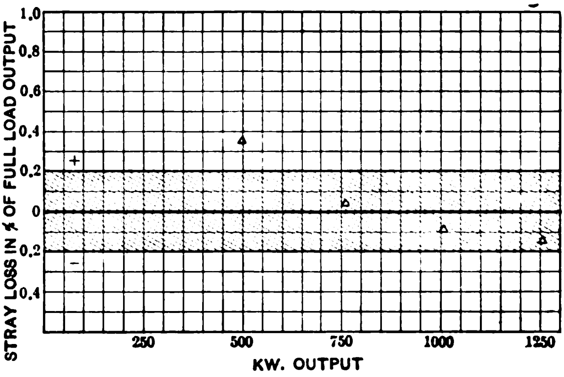
An occasional observer may be found who cannot record the indications of his instruments even with impartial inexactness. Such a one must be located and replaced before the test can be satisfactorily concluded.



CURVE 1



CURVE 2



CURVE 3

Reference to Curve 1, will show that redeterminations at 50 per cent load made on succeeding days checked very closely because presumably the conditions of bearing and commutator did not differ. This is also shown on Curve 2, at 100 per cent load.

These points are referred to simply to emphasize the fact that the load loss values could, as stated, be brought closely within the belts, if the losses determinable at no load and which vary within relatively wide limits from time to time, had been ascertained at the same time that the efficiency point was taken.

TABLE I
THREE-UNIT SET—1135-KV-A., 6600-VOLT, SYNCHRONOUS MOTOR DIRECT-CONNECTED TO TWO 500-KW., 125-VOLT DIRECT-CURRENT GENERATORS

50 per cent load	Obs. No.	Kw.		Per cent efficiency	Deviation from mean
		Input	Output		
	1	614.2	502	81.8	1.1
	2	583.3	486.8	83.5	0.6
	3	562.4	464	82.6	0.3
	4	599.8	497	83.1	0.2
	5	598.2	496	83	0.1
	6	590.8	494.3	83.7	0.8
	7	584.7	490.5	83.8	0.9
	8	602.3	493.5	82	0.9
	9	588.8	489.5	83.1	0.2
	10	602.6	495.5	82.3	0.6
Average		592.71	490.91	82.9	$\frac{0.57}{\sqrt{10} \times 82.9} = \pm 0.22\%$

Test output		Seg. loss		Seg. loss input	
490.91	+	100.8	=	591.71	$\frac{490.91}{591.71} = 83\%$ seg. loss eff.

Test input		Seg. loss input		Stray loss
592.71	—	591.71	=	+ 1.0 kw. = +0.10% of normal load output.

TABLE II

THREE-UNIT SET—1135-KV-A., 6600-VOLT SYNCHRONOUS MOTOR DIRECT CONNECTED TO TWO 500-KW., 125-VOLT, DIRECT-CURRENT GENERATORS

50 per cent load	Obs. No.	Kw.		Per cent eff.	Deviation from mean
		Input	Output		
	1	589.3	470.5	80	2.8*
	2	611.3	508	83.2	0.1
	3	597	494.5	83	0.1
	4	605.6	505	83.5	0.4
	5	612.2	512	83.8	0.7
	6	599.8	495.7	82.6	0.5
	7	604.4	499	82.7	0.4
	8	602.4	499	83	0.1
	9	598.4	498.5	83.2	0.1
	10	611.4	507	82.9	0.2
Average	(without 1)	604.72	502.07	82.8	$\frac{0.3}{\sqrt{9} \times 82.8} = \pm 0.12\%$

Test output   Seg. loss   Seg. loss input

502.07 + 101.2 = 603.27 $\frac{502.07}{603.27}$ = 83.2% seg. loss eff.

Test input   Seg. loss input   Stray loss

604.72 — 603.27 = +1.45 kw. = +0.145% of normal load output

* Values in these tables marked with an asterisk rejected on account of being over three times greater than the average.

TABLE III

THREE-UNIT SET—1135-KV-A., 6600-VOLT, SYNCHRONOUS MOTOR DIRECT-CONNECTED TO TWO 500-KW., 125-VOLT, DIRECT-CURRENT GENERATORS

75 per cent load	Obs. No.	Kw.		Per cent eff.	Deviation from mean
		Input	Output		
	1	879.92	766.5	87.1	1.1
	2	881.8	760	86.2	0.2
	3	942.9	728	77.3	8.2*
	4	892.8	770.3	86.4	0.4
	5	881.9	760.9	86.3	0.3
	6	896.8	766.1	85.4	0.6
	7	896.8	771.1	85.9	0.1
	8	877.4	758.8	86.5	0.5
	9	873.8	752.8	86.2	0.2
	10	891.3	762.3	85.6	0.4
	11	912.1	781	85.6	0.4
	12	879.9	750.4	86.5	0.5
	13	896.8	766.3	85.4	0.6
	14	875.7	744.8	85.1	0.9
	15	853.5	742.4	87	1
Average	(without 3)	885.03	761	86.05	$\frac{0.5}{\sqrt{14} \times 86.05} = \pm 0.15\%$

Test output   Seg. loss   Seg. loss input

761 + 119 = 880 $\frac{761}{880}$ = 86.5% seg. loss eff.

Test input   Seg. loss input   Stray loss

885.03 — 880 = + 5.03 kw. = +0.503 % of normal load output

TABLE IV

THREE-UNIT SET—1135-KV-A., 6600-VOLT, SYNCHRONOUS MOTOR DIRECT-CONNECTED TO TWO 500-KW., 125-VOLT, DIRECT-CURRENT GENERATORS

Full load	Obs.	Kw.		Per cent eff.	Deviation from mean
		Input	Output		
	1	1140	1003	87.8	0.2
	2	1120	1000	89.5	1.9
	3	1157	1003	86.7	0.9
	4	1196	1009	84.2	3.6*
	5	1142	993	87	0.6
	6	1172	1009	86	1.6
	7	1156	1016	87.5	0.1
	8	1142	1000	87.5	0.1
	9	1138	1028	90.5	2.7*
	10	1138	1035	90.9	3.1*
	11	1167	1041	89.2	1.6
	12	1156	1018	88	0.4
	13	1146	1003	87.5	0.1
	14	1169	1022	87.5	0.1
	15	1145	996	87.1	0.5
	16	1161	1016	90.6	2.8*
	17	1120	987	88.2	0.6
	18	1128	984	87.2	0.4
	19	1195	1029	86	1.6
	20	1157	1014	87.6	0.0
	21	1117	993	89	1.4
	22	1120	986	88.7	1.1
	23	1160	1022	88.3	0.7
	24	1139	1012	88.9	1.3
	25	1142	1012	87.6	0.0
	26	1198	1025	85.6	2
	27	1169	1019	87.2	0.4
	28	1140	1003	88	0.4
	29	1150	1009	87.6	0.0
	30	1157	1016	87.8	0.2
	31	1142	1004	87.9	0.3
	32	1145	1006	87.8	0.2
	33	1161	1001	86.5	1.1
Average	(without 4, 9, 10, 16)	1150	1007.8	87.6	$\frac{0.69}{\sqrt{29} \times 87.6} = \pm 0.14\%$

Test output		Seg. loss		Seg. loss input	
1007.8	+	140.5	=	1148.3	$\frac{1007.8}{1148.3} = 87.76\%$ seg. loss eff.

Test input		Seg. loss input		Stray loss
1150	—	1148.3	=	+1.7 kw. = +0.17% of normal load output.

Brush and bearing friction including windage = 23.98 kw.

TABLE V

TWO-UNIT SET—1120-KV-A., 6600-VOLT SYNCHRONOUS MOTOR CONNECTED TO A 1000-KW., 250-VOLT, DIRECT-CURRENT GENERATOR

50 PER CENT LOAD

Obs. No.	Input $\text{Wm.} + \frac{\text{kw. field}}{\text{ratio trans.}}$	Output millivolts × volts	Ratio	Deviation from mean
1	342.8	10600	30.91	0.213
2	339.8	10420	30.72	0.023
3	340.8	10450	30.65	0.047
4	339.3	10390	30.61	0.087
5	339.3	10380	30.60	0.097
6	338.8	10350	30.58	0.117
7	343.8	10610	30.92	0.223
8	344.8	10530	30.59	0.107
Average	341.2	10466	30.69	$\frac{0.1146}{\sqrt{8} \times 30.69} = \pm 0.132\%$

Ratio of trans. 1789.4

Mult. fact. of shunts 48.6

Kw. 610.1 508 $\frac{508}{610.1} = 83.3\%$ eff. input-output.

Test output		Seg. loss		Seg. loss input	
508	+	104	=	612	$\frac{508}{612} = 83\%$ eff. seg. loss.

Test input		Seg. loss input		Stray loss	
610.1	—	612	=	−1.9	= −0.19% of normal load output.

TABLE VI

TWO-UNIT SET—1120-KV-A., 6600-VOLT, SYNCHRONOUS MOTOR CONNECTED TO A 1000-KW., 250-VOLT DIRECT-CURRENT GENERATOR

50 PER CENT LOAD

Obs. No.	Input Wm. + $\frac{\text{kw. field}}{\text{ratio trans.}}$	Output millivolts × volts	Ratio	Dev. from mean
1	342.25	9980	29.15	0.188
2	346.25	10200	29.43	0.092
3	341.25	10080	29.55	0.212
4	340.25	9990	29.35	0.012
5	337.25	9850	29.21	0.128
Average	341.65	10020	29.388	$\frac{0.1264}{\sqrt{5} \times 29.388}$ $= \pm 0.193\%$

Ratio of trans. 1784

Mult. fact of shunts 50.6

Kw. 608.9 504.4 $\frac{504.4}{608.9} = 82.9\%$ eff. input-output.

Test output		Seg. loss		Seg. loss input	
504.4	+	104	=	608.4	$\frac{504.4}{608.4} = 83\%$ eff. seg. loss.

Test input		Seg. loss input		Stray loss	
608.9	—	608.4	=	+0.5	= +0.5% of normal load output.

TABLE VII

TWO-UNIT SET—1120-KV-A., 6600-VOLT SYNCHRONOUS MOTOR CONNECTED TO A 1000-KW, 250-VOLT, DIRECT-CURRENT GENERATOR

75 PER CENT LOAD

Obs. No.	Input $\text{Wm.} + \frac{\text{kw. field}}{\text{ratio trans.}}$	Output millivolts × volts	Ratio	Dev. from mean
1	496.4	15700	31.60	0.145
2	494.4	15650	31.70	0.045
3	501.4	15910	31.78	0.035
4	499.4	15890	31.80	0.055
5	499.4	15850	31.79	0.045
6	495.4	15730	31.70	0.045
7	495.4	15750	31.78	0.035
8	494.4	15710	31.81	0.065
Average	497.02	15774	31.745	$\frac{0.0587}{\sqrt{8} \times 31.745} = \pm 0.065\%$

Ratio of trans. 1778.6

Mult. fact. of shunts 48.6

Kw. 884.1 768 $\frac{768}{884.1}$ = 86.8% eff. input-output.

Test output 768 + Seg. loss 114.6 = Seg. loss input 882.6 $\frac{768}{882.6}$ = 87% eff. seg. loss.

Test input 884.1 — Seg. loss input 882.6 = Stray loss +1.5 = + 0.15% of normal load output.

TABLE VIII

TWO-UNIT SET—1120-KV-A., 660-VOLT, SYNCHRONOUS MOTOR CONNECTED TO A 1000-KW., 250-VOLT, DIRECT-CURRENT GENERATOR

75 PER CENT LOAD

Obs. No.	Input Wm. + $\frac{\text{kw. field}}{\text{ratio trans.}}$	Output millivolts × volts	Ratio	Dev. from mean.
1	494.6	15110	30.59	0.134
2	494.6	15100	30.57	0.114
3	489.6	14850	30.39	0.066
4	492.6	14900	30.23	0.226
5	493.6	15040	30.50	0.044
Average	493	15000	30.456	$\frac{0.1168}{\sqrt{5} \times 30.456}$ $= \pm 0.171\%$

Ratio of trans.	1777.3		
Mult. fact. of shunts		50.4	
Kw.	876.4	756	$\frac{756}{876.4} = 86.4\%$ eff. input-output.

Test output 756 + Seg. loss 114.2 = Seg. loss input 870.2 $\quad \frac{756}{870.2} = 86.9\%$ eff. seg. loss.

Test input 876.4 — Seg. loss input 870.2 = Stray loss +6.2 = +0.62% of normal load output.

TABLE IX

TWO-UNIT SET—1120-KV-A., 6600-VOLT, SYNCHRONOUS MOTOR DIRECT-CONNECTED TO A 1000-KW., 250-VOLT, DIRECT-CURRENT GENERATOR

NORMAL LOAD

Obs. No.	Input $\text{Wm.} + \frac{\text{kw. field}}{\text{ratio trans}}$	Output millivolts × volts	Ratio	Dev. from mean
1	675.3	21800	32.23	0.165
2	647.3	20780	32.10	0.035
3	656.3	21000	32	0.065
4	658.3	21110	32.09	0.025
5	657.3	21070	32.03	0.035
6	656.3	21030	32.01	0.055
7	655.3	21030	32.10	0.035
8	653.3	20970	32.11	0.045
9	655.3	21000	32.01	0.055
10	663.3	21150	31.89	0.175
11	657.3	21040	32.01	0.055
12	660.3	21200	31.99	0.075
13	663.3	21400	32.29	0.235
14	658.3	21190	32.19	0.125
15	661.3	21100	31.92	0.145
Average	658.57	21125	32.065	$\frac{0.0884}{\sqrt{15} \times 32.065}$ = ±0.071%

Ratio of trans. 1775.3

Mult. fact. of shunts 48.63

Kw.	1169.2	1027.1	$\frac{1027.1}{1169.2}$ = 87.85% eff. input-output

Test output + Seg. loss = Seg. loss input

1027.1 + 129.2 = 1 156.3 $\qquad \frac{1027.1}{1156.3}$ = 88.8% eff seg. loss.

Test input — Seg. loss input = Stray loss

1169.2 — 1156.3 = +12.9 = +1.29% of normal load output.

TABLE X

TWO-UNIT SET—1120-KV-A., 6600-VOLT, SYNCHRONOUS MOTOR DIRECT-CONNECTED TO A 1000-KW., 250-VOLT DIRECT-CURRENT GENERATOR

NORMAL LOAD

Obs. No.	Input $\text{Wm.} + \frac{\text{kw. field}}{\text{ratio trans.}}$	Output millivolts × volts	Ratio	Dev. from mean
1	659.9	21570	32.70	0.58*
2	662.9	21220	32.05	0.00
3	653.9	20940	32.09	0.04
4	658.9	21990	32.19	0.14
5	654.9	20980	32.03	0.02
6	655.9	21080	32.12	0.07
7	657.9	21200	32.21	0.16
8	662.9	21060	31.08	0.25
9	659.9	21180	32.09	0.04
10	656.9	20960	31.90	0.15
Average (without No. 1)	658.2	21179	32.05	$\frac{0.097}{\sqrt{9} \times 32.05} = \pm 0.107\%$

Ratio of trans. 1775.3

Mult. fact. of shunts 48.63

Kw. 1170.1 1027.7 $\frac{1027.7}{1170.1} = 87.8\%$ eff. input-output.

Test output 1027.7 + Seg. loss 129.2 = Seg. loss input 1156.9 $\frac{1027.7}{1156.9} = 88.6\%$ eff. seg. loss.

Test input 1170.1 — Seg. loss input 1156.9 = Stray loss +13.2 = + 1.32% of normal load output

TABLE XI

TWO-UNIT SET—1120-KV-A., 6600-VOLT, SYNCHRONOUS MOTOR, DIRECT-CONNECTED TO A 1000-KW., 250-VOLT, DIRECT-CURRENT GENERATOR

NORMAL LOAD

Obs. No.	Input Wm. + $\frac{\text{kw. field}}{\text{ratio trans.}}$	Output millivolts × volts	Ratio	Dev. from mean
1	654.9	20250	30.98	0.09
2	647.9	20100	31	0.11
3	650.9	20210	31.02	0.13
4	650.9	20160	30.95	0.06
5	650.9	20150	30.95	0.06
6	655.9	20166	30.75	0.14
7	654.9	20140	30.75	0.14
8	654.9	20250	30.95	0.06
9	654.9	20220	30.90	0.01
10	653.9	20210	30.95	0.06
11	651.9	20120	30.85	0.04
12	656.9	20320	30.90	0.01
13	654.9	20280	30.98	0.09
14	658.9	20300	30.82	0.07
15	655.9	20320	30.95	0.06
16	652.9	20100	30.80	0.09
17	655.9	20240	30.85	0.04
18	652.9	20100	30.80	0.09
19	649.9	20000	30.79	0.10
20	649.9	20050	30.82	0.07
Average	653.5	20184	30.89	$\frac{0.076}{\sqrt{20} \times 30.89} = \pm 0.055\%$

Ratio of trans. 1775.3

Mult. fact. of shunts 48.63

Kw. 1159.7 1017.3 $\frac{1017.3}{1159.7} = 87.7\%$ eff. input-output

Test output		Seg. loss		Seg. loss input	
1017.3	+	129.2	=	1146.5	$\frac{1017.3}{1146.5} = 88.7\%$ eff. seg. loss.

Test input		Seg. loss input		Stray loss	
1159.7	—	1146.5	=	+13.2	= +1.32% of normal load output

Brush and bearing friction including windage 28.87 kw.

TABLE XII

THREE-UNIT SET—1450-KV-A., 2300-VOLT, SYNCHRONOUS MOTOR DIRECT-CONNECTED TO TWO 500-KW., 1200-VOLT, DIRECT-CURRENT GENERATORS

50 PER CENT LOAD

Obs. No.	Input W_1	Input W_2	Input $W_1 + W_2$	Output kw.	Ratio	Deviation from mean
1	172	67	239	496.37	2.074	0.024
2	172	70	242	513	2.118	0.020
3	170	70	240	493.46	2.052	0.046
4	170	67	237	499.80	2.108	0.010
5	174	69	243	511.65	2.182	0.076*
6	171	68	239	502.82	2.101	0.003
7	170	66	236	493.71	2.088	0.010
8	171	67	238	503.94	2.115	0.017
9	168	65	233	491.14	2.106	0.008
10	170	67	237	502.88	2.120	0.012
Average (Without 5)	170.47	67.44		499.66	2.098	$\frac{0.0167}{\sqrt{9}\times 2.098} = 0.265\%$

Phase angle correction factor	0.9982	0.9705		
C. T. ratio	120.4	120.3		
P. T. ratio	19.88	19.90	Kw. input	
Kw	407.3	156.69	563.99	
Sep. exc. field			7.48	
Total input			571.47	
Total output				499.66

$\frac{499.66}{571.47}$ = 87.43% eff. input-output

Test output 499.66 + Seg. loss 68.42 = Seg. loss input 568.08

$\frac{499.66}{568.08}$ = 87.95% eff seg. loss

Test input 571.47 — Seg. loss input 568.08 = Stray loss +3.39 kw. = +0.34% of normal load output

TABLE XIII

THREE-UNIT SET—1450-KV-A., 2300-VOLT, SYNCHRONOUS MOTOR DIRECT CONNECTED TO TWO 500-KW., 1200-VOLT, DIRECT-CURRENT GENERATORS

75 PER CENT LOAD

Obs. No.	Input			Output kw.	Ratio	Deviation from mean
	W_1	W_2	W_1+W_2			
1	253	103	356	770.17	2.162	0.005
2	250	98	348	745.05	2.14	0.017
3	250	99	349	751.56	2.15	0.007
4	250	97	347	755.58	2.175	0.018
5	250	98	348	748.82	2.147	0.010
6	250	97.5	347.5	751.79	2.164	0.007
7	249	97.5	346.5	743.78	2.143	0.014
8	249	97.5	346.5	745.96	2.152	0.005
9	250	98	348	757.77	2.176	0.019
10	250	97.5	347.5	751.10	2.163	0.006
Average	250.1	98.3		752.158	2.157	$\frac{0.0108}{\sqrt{10} \times 2.167} = \pm 0.1586\%$

Phase angle corr. factor	0.99804	0.9719	
C. T. ratio	120.1	120	
P. T. ratio	19.88	19.9	Kw. input
Kw.	596.1	228.13	724.23
Sep. exc. field			8.085
Total input			832.315
Total output			752.158

$$\frac{752.158}{832.315} = 90.37\% \text{ eff input-output}$$

Test output		Seg. loss		Seg. loss input
752.158	+	79.871	=	832.029

$$\frac{752.158}{832.029} = 90.508\% \text{ eff. seg. loss.}$$

Test input		Seg. loss input		Stray loss
832.315	—	832.029	=	+0.286 kw. = +0.286% of normal load output

TABLE XIV

THREE-UNIT SET—1450-KV-A., 2300-VOLT, SYNCHRONOUS MOTOR DIRECT-CONNECTED TO TWO 500-KW., 1200-VOLT, DIRECT-CURRENT GENERATORS

NORMAL LOAD

Obs. No.	Input			Output kw.	Ratio	Deviation from mean
	W_1	W_2	W_1+W_2			
1	338	132	470	1021.8	2.178	0.001
2	330	124	454	992.7	2.183	0.004
3	331	130	461	1001	2.172	0.007
4	333	137.5	470.5	1026.3	2.181	0.002
5	330	137	467	1020.1	2.183	0.004
6	330	136	466	1014.9	2.179	0.000
7	330	137	467	1020.9	2.183	0.004
8	326	131	457	994.7	2.173	0.006
9	330	131	461	1003.3	2.176	0.003
10	330	131	461	1002.8	2.175	0.004
11	330	132.5	462.5	1010.8	2.187	0.010
12	332	131	463	1004.9	2.173	0.006
13	334	134	468	1020.2	2.182	0.003
14	330	132	462	1005.6	2.179	0.000
15	329	132	461	1016	2.204	0.024*
16	331	134	465	1011.6	2.175	0.004
17	330	132.5	462.5	1005.1	2.175	0.004
18	329	128	457	1000.7	2.190	0.011
19	330	131.5	461.5	998.7	2.162	0.017
20	330	131.5	461.5	1001.2	2.189	0.011
Average (without 15)	330.74	132.37		1008.28	2.179	$\frac{0.0053}{\sqrt{19}\times 2.179}$
						= ±0.574%

Phase angle corr. factor	0.99804	0.9719	
C. T. ratio	119.8	119.8	
P. T. ratio	19.88	19.9	Kw. input
Kw.	785.98	306.55	1092.53

Sep. exc. field 10.832

Total input 1103.36

Total output 1008.28

$\frac{1008.28}{1103.36}$ = 91.59% eff. input-output

Test output 1008.28 + Seg. loss 96.068 = Seg. loss input 1104.348

$\frac{1008.28}{1104.348}$ = 91.34% eff. seg. loss.

Test input 1103.36 — Seg. loss input 1104.348 = Stray loss − 0.988 = —0.0988% of normal load.

Brush and bearing friction including windage = 18.55 kw.

TABLE XV

THREE-UNIT SET—1450-KV-A., 2300-VOLT, SYNCHRONOUS MOTOR DIRECT-CONNECTED TO TWO 500-KW., 1200-VOLT, DIRECT-CURRENT GENERATORS

125 PER CENT LOAD

Obs. No.	Input			Output kw.	Ratio	Deviation from mean
	W_1	W_2	$W_1 + W_2$			
1	407	165	572	1259.69	2.200	0.024
2	410	168	578	1259.32	2.181	0.005
3	407	168	575	1250.79	2.178	0.002
4	410	168	578	1249.87	2.164	0.012
5	405	167	572	1246.75	2.178	0.002
6	405	167	572	1267.54	2.216	0.036*
7	412	169	581	1267.25	2.181	0.005
8	414	170	584	1252.96	2.148	0.028
9	406	167	573	1248.80	2.180	0.004
10	412	169	581	1262.16	2.171	0.005
Average (without 6)	409.2	167.9		1255.29	2.176	$\frac{0.0097}{\sqrt{9} \times 2.176}$
						= 0.148%

Phase angle corr. factor	0.9980	0.9719	
C. T. ratio	119.6	119.6	
P. T. ratio	19.88	19.90	Kw. input
Kw.	970.96	388.37	1359.33
Sep. exc. field			12.338
Total input			1371.668

$$\frac{1255.29}{1371.668} = 91.512\% \text{ eff. input-output}$$

Total output 1255.29

Test output		Seg. loss		Seg. loss input
1255.29	+	118.025	=	1373.315

$$\frac{1255.29}{1373.315} = 91.409\% \text{ eff. seg. loss.}$$

Test input		Seg. loss input		Stray loss
1371.668	—	1373.315	=	—1.647 kw. = —0.165% of normal load output

SECTION II

PROCEEDINGS

of the

American Institute

of

Electrical Engineers

Papers, Discussions and Reports

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THERMOCOUPLES AND RESISTANCE COILS FOR THE DETERMINATION OF LOCAL TEMPERATURES IN ELECTRICAL MACHINES

BY

J. A. CAPP and L. T. ROBINSON

Presented under the auspices of the

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THERMOCOUPLES AND RESISTANCE COILS FOR THE DETERMINATION OF LOCAL TEMPERATURES IN ELECTRICAL MACHINES

BY J. A. CAPP AND L. T. ROBINSON

ABSTRACT OF PAPER

The paper discusses different devices for measuring temperatures in electrical machines and points out their various sources of error, and also the limitations of the uses of mercury and alcohol thermometers, thermocouples and resistance coils. Fluid thermometers can generally measure only surface temperatures, and temperatures of rotating parts must be measured after they come to rest, thereby introducing large chances of error due to equalization or rapid changes of temperature, slow rate of indication of thermometers, small contact between the bulb and the surface to be measured, emergent stem, etc.

In the measurement of temperature by the electrical resistance method either the windings of the machine itself or fine wire coils placed in or about the windings are employed. In using the coils of the machine, the result depends upon the accuracy with which the coefficient of change of resistance of the copper with temperature is known. This method, of course, gives only the average temperature of the whole length of the winding and does not indicate the temperature of any part of the winding. Where coils of fine copper are used highly accurate measurements are possible, as the coefficient of temperature of the wire may be accurately known. The extent of the coil determines the extent to which the measurement is local. For accurate determinations, some sort of bridge for determining the resistance is required.

The thermocouple is the most accurate device for measuring local temperatures, as the e.m.f. generated is a function of the difference in temperature between the junction of the wires of the couple and their free ends, and the temperature of the free ends can be accurately controlled. Thermocouples require the use of precision meters for reading their indications, and potentiometer arrangements may be applied to obtain any desired degree of accuracy.

Ordinary thermometry is the simplest, quickest and least accurate method of temperature measurement, and usually applies only to surface conditions. The choice between the electrical methods of temperature measurement is largely determined by the ease of application in any particular case. The thermocouple will give the most rapid indications, although the resistance method is almost as rapid if the coil is of right proportions and is intimately applied to the parts whose temperature is to be measured.

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THERMOCOUPLES AND RESISTANCE COILS FOR THE DETERMINATION OF LOCAL TEMPERATURES IN ELECTRICAL MACHINES

BY J. A. CAPP AND L. T. ROBINSON

Temperatures of electrical machines may be determined in either of the two usual ways, namely, by fluid expansion thermometers, or by electrical thermometers, which may be either of the resistance or thermoelectric type.

Fluid thermometers are usually available only for the determination of surface temperatures. In the case of rotating parts they can usually be applied only after the parts have come to rest. The thermometer, therefore, will indicate a temperature which may not be that existing on the surface during rotation, but may be higher or lower, depending upon the flow of heat during equalization. Thermometers vary greatly in the rate with which they indicate the temperature to which the bulb may be subjected. This, together with the possible error in indication, due to the equalization of temperature just mentioned, may bring about considerable errors in the results. Ordinarily the thermometer bulb is held in contact with the surface whose temperature is to be measured, by means of some plastic material, such as putty, which in itself is of relatively low heat conductivity. If the temperature changes which take place during equalization are relatively rapid, there is here a further possibility of error.

Unless some such material as putty is used, the temperature indications of the thermometer will be low, because there is not sufficiently intimate contact between the bulb and the surface whose temperature is to be measured.

As ordinarily supplied by the makers, either mercury or alcohol thermometers are calibrated with either the entire stem immersed in a liquid or atmosphere of the temperature to be measured, or at least with the stem immersed to the point of indication. In other words, the thermometers are customarily supplied with their scale adjusted for full scale immersion. In use in determining the temperature of a surface, only the bulb, or at most but a short portion of the stem above the bulb, is exposed to the temperature to be measured. There have been worked out formulas for the correction of the emergent stem, as it is called, but these are cumbersome, and, indeed, such corrections are comparatively seldom made in ordinary measurements of temperature. The correction for the emergent stem may amount to as much as two to four degrees at 80 to 100 deg. cent., the reading in such case, of course, being low. It is possible to obtain thermometers specially calibrated with only the bulb and a very short portion of the stem immersed in the liquid or hot atmosphere used for calibration. Such thermometers when calibrated with, say, 2 in, (50.8 mm.) immersion, may safely be used under ordinary conditions, where the temperature of the emergent stem is approximately that of the ordinary room temperature at which the calibration was done. The error due to failure to correct for emergent stem is far larger than the probable error of even the ordinary commercial thermometer when used as calibrated. In fact, such commercial thermometers are readily obtainable with an accuracy of four to five tenths of one degree at 100 deg. cent. Of course the error due to the emergent stem is entirely independent of the inherent accuracy of the thermometer itself.

The second method of measuring temperatures, or the electrical resistance thermometer, is susceptible of a variety of applications. Essentially it depends upon the accuracy with which the coefficient of change of resistance with temperature is known. The simplest and most obvious application of this method is the use of windings of the motor or generator itself. In such case, the material being copper, the temperature coefficient is assumed to be 0.00428 at 0 deg. cent., 0.00386 at 25 deg. cent., and the accuracy of the results obtained is dependent upon whether the actual copper used in the winding has exactly this temperature coefficient.

Commercial copper, such as would ordinarily be used in electrical machines of the kind being considered, would very seldom vary enough from standard conductivity and hence from the temperature coefficients belonging to 100 per cent conductivity copper to influence the correctness of the temperature determination more than one deg. cent. between the limits of 25 and 100 deg. cent. This question of definitely known temperature coefficient is, therefore, not of importance in temperature determinations using the entire winding, but in resistance thermometers for accurate work, in which prepared coils are used, this small error is easily taken care of.

The error, then, in determining temperature by resistance of windings, can be considered as governed almost entirely by the ability to determine accurately their resistance. The error is about three deg. cent. for one per cent variation from correct resistance values. When using workshop means for determining the resistance it is reasonable to expect measurements within one per cent and, therefore, the temperature should be known by this means within three or four deg. cent., if the initial temperature and resistance are known. The temperature rise of a winding of a machine determined by resistance measurements is, of course subject to still further uncertainty due to the difficulty, especially in large machines, of knowing definitely the temperature of the winding when the cold resistance is observed.

The increase in resistance which is used as the measure of temperature corresponds to the average increase in temperature of the entire winding throughout its length, and the results obtained do not indicate the temperature at any part of the winding. There may be large differences in different parts of the same conductor.

Another application of the resistance method of measurement consists in the placing of fine wire coils at any desired location in or about the winding. Such coils may be placed with thin insulation practically in immediate contact with the conductor, or they may be embedded in the insulation at any desired depth. In such case highly accurate measurements are possible because the actual temperature coefficient of the piece of wire used as the measuring device is easily known. Here again, the increase in resistance is the result of the average temperature rise in the immediate vicinity of the measuring coil. The extent of the coil, therefore, determines the extent to which the measurement is local. Such a device, by bringing leads from the resistance coil to collector rings, may be made to measure temperatures while the parts in which the measuring coil is embedded are rotating.

The practical value of resistance thermometers for high temperatures is doubtful. Base metal coils are permanently changed in resistance by continued use and if the more expensive platinum windings do not suffer from this cause, they are at least subject to mechanical damage. For the moderate temperatures being considered there is no danger from oxidation and, therefore, copper or some similar resistance coil may be used, and it may be embedded in the machine during construction and thus well protected from mechanical damage or it can be made up in form, to be inserted later. The temperature coefficient of these coils can be determined with any desired degree of accuracy before they are inserted and the resistance can be measured within any required limits when they are in place. For precision testing it is quite possible to obtain results without difficulty within a part of a degree, using some sort of bridge for determining the resistance; the bridge may be graduated to read directly in temperature. For workshop and central station applications of resistance thermometers, direct-reading temperature indicating attachments, in the form of indicating switchboard instruments, may be used and satisfactory accuracy obtained. The inserted resistance coils should be reasonably non-inductive and precaution should be taken to have them so protected by insulation that may not be the cause of damaging the windings of any machine in which they are used, or the means of transferring high tension to the switchboard instruments connected with them or to the low-tension d-c. net work which supplies current to operate the device. There can be no question of the reliability of temperature obtained by this means, representing the average of the region occupied by the coil, but no matter what system of connections is chosen and what safety devices are applied in connection with it when the coil is embedded in or between high-tension windings it is difficult to dismiss entirely the feeling that an added element of danger to the machine and operator must be reckoned with.

The second electrical method of determining temperature is that using the thermocouple. Since the electromotive force generated by the thermocouple is a function of the difference between the temperature of the junction of the wires forming the couple and that of their free ends, it is obvious that the thermocouple may measure the temperature more nearly locally than any other device.

This same fact requires that there be accurate control of the temperature of the free ends, or the cold end temperature, as it is commonly called. With this temperature controlled by immersion of the free ends in oil or other equally simple means it is possible to determine the electromotive force with great accuracy, and because of the ease with which a thermocouple may be calibrated for use at relatively moderate temperatures, this method of measurement is a very satisfactory one. One of its most interesting applications is in the determination of the temperature of the rubbing surfaces of a bearing.

It is easily possible to provide a minute junction with very thin insulation and embed it in the babbitt metal in a bearing, so that it is but a fraction of an inch below the actual surface of the babbitt, and by this means the temperature of the actual rubbing surface of bearings, at predetermined points in the journal, have been determined very satisfactorily. By similar means the temperature of any part of the apparatus may be determined if the parts are still. Measurements may also be made with the apparatus in operation. In the case of rotating parts, however, it is necessary to provide slip rings of such materials as to avoid disturbing or parasitic electromotive forces. Artificially prolonging the couple in this way permits the control of the cold end temperature and the taking of readings during operation.

For the moderate temperatures encountered in electrical apparatus it is not necessary to go to the expensive rarer metals which are required for similar thermocouples used for pyrometers at high temperatures. Copper with constantan makes a satisfactory couple, yielding a readable electromotive force even with small differences in temperature. In no case, however, with the ordinary differences in temperature to be expected, will any of the thermocouples commonly used yield sufficient electromotive force to permit the use of ordinary switchboard instruments for reading, but instead the measurements must be made by instruments equivalent to galvanometers.

Thermocouples may be calibrated to give accurate indications of temperature and when used with directly indicating instruments results within a degree or two may be expected. For more refined work potentiometer arrangements may be applied and by this means any desired degree of precision can be reached.

Of the methods of measurements mentioned, ordinary thermometry is the simplest, quickest, and most easily performed, but it is the least accurate. It is usually applicable only to surface conditions, and can seldom be used to determine anything concerning the internal temperatures of the apparatus. The choice between the electrical resistance method and the thermoelectric method is largely determined by conditions, and ease of application in the individual case. Both methods, compared with ordinary thermometry, are somewhat more difficult of application and require more delicate apparatus than the ordinary meters used in commercial testing. In rapidity of indication the thermocouple will rank first, if properly applied, though the indications of the electrical resistance thermometer will be nearly as rapid, provided the resistance coil is of right proportions and applied in intimate thermal contact with the parts whose temperature is to be measured.

GENERATOR AND PRIME MOVER CAPACITIES

BY

DAVID B. RUSHMORE and ERIC A. LOF

Presented under the auspices of the

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GENERATOR AND PRIME MOVER CAPACITIES

BY DAVID B. RUSHMORE AND ERIC A. LOF

Abstract of Paper

Electric generators are of necessity driven by prime movers and the combination must be treated as a single unit when considering the questions of ratings and capacities. The importance of the proper adaptation of the capacities is fully emphasized by the fact that there are in operation in many stations in this country, units in which the output is unnecessarily limited by a discrepancy in the ratings, in that the prime mover is either too small or too large for the generator. The latter may, for example, be designed for unity power factor, while the actual operating power factor may be 0.8, in which case the full capacity of the prime mover can not be utilized.

In the past every effort was made to adjust the ratings of the generators to the station load curves, and the result was that overload capacities of 25, 50 or even 100 per cent had to be guaranteed, usually for a period of two hours. With the growth of the generating station and the improved load conditions this practice is now becoming more and more obsolete and the units are being rated on a maximum or, more properly called, constant continuous rating, which should not be exceeded except during momentary peaks. Steam turbine units have been rated according to this method for some time past, and with entirely satisfactory results. It is also becoming quite common in connection with waterwheel-driven units, and there seems to be no reason why it should not prove to be equally satisfactory for hydroelectric plants, especially for low heads, where the waterwheel efficiency falls off rapidly as the power is reduced below the normal full load. Exceptions to this may, however, be found, as, for example, where heavy short-period peak loads must be provided for, in which case it may be advisable to select a generator having a corresponding overload capacity. For the sake of standardization it seems, however, desirable to give all generators a maximum constant continuous rating at a certain specified temperature.

A paper to be presented at the Midwinter Convention of the American Institute of Electrical Engineers, New York, February 26–28, 1913.

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GENERATOR AND PRIME MOVER CAPACITIES

BY DAVID B. RUSHMORE AND ERIC A. LOF

The chief distinctive characteristic of electrical apparatus is that its capacity is limited by thermal considerations. Electrical generators are of necessity driven by prime movers and the combination must be treated as a single unit when considering the questions of ratings and capacities. Such prime movers as steam engines, steam turbines, gas engines and waterwheels have various limitations regarding their output which must be considered in connection with that of the electric generators they are driving. The proper adjustment of ratings for generators and prime movers with these different limitations as determined by the conditions of service, is the object of this paper. In direct-current generators the limitation imposed by commutation has almost entirely been removed by the use of interpoles. With alternators as now constructed, the limitation of output due to regulation of the machine is but seldom found; therefore the question of heating may be considered as the important factor for consideration. Under certain conditions of violently fluctuating loads or intermittent service, the questions of commutation and regulation may, however, become of considerable importance.

The capacity of an alternator is limited not only by the actual energy load which the machine is carrying, but also by the power factor of such load. The additional heating at low power factors and constant power is due to the wattless component of the armature current and also to the additional field current necessary to counteract it. In many cases it is possible to predetermine approximately the power factor under which the generators will operate, and the special design to meet this particular condition is largely desirable. The curves in Fig. 1 show the different conditions of load and power factor which will produce the limiting conditions of heating in an inductor alternator. The synchronous impedance here is considered to consist almost entirely of reactance.

The importance of the proper adaptation of capacities of generators and prime movers is emphasized by the fact that there are in operation in many stations in this country units in which the output is unnecessarily limited by an improper rating or design of either the generator or prime mover. The generator may be designed for unity power factor while the condition of operation may be the power factor 0.8, in which case only a part of the prime mover capacity can be utilized. In not a few instances in hydroelectric stations, the waterwheel is either too small or too large for the generator and a like result ensues. In some hydroelectric plants where the generators are installed to handle peak loads, this maladjustment of ratings is a necessity, but with most of the larger systems it is unnecessary to run machines

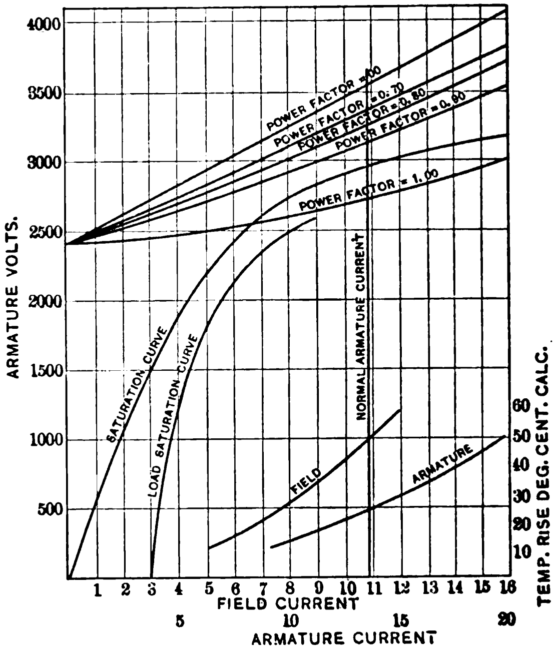

FIG. 1—CHARACTERISTIC CURVES OF INDUCTION ALTERNATOR.

except at or near their maximum ratings. In the past, every effort was made to adjust the ratings of generators to the load curves and we had 25, 50 and 100 per cent overload guarantees for certain apparatus. Experience and better load conditions have changed this to a maximum rating which has become possible largely through the growth in the size of stations and systems.

The speeds of engine-driven units, both gas and steam, have become nearly standardized, and turbine-driven sets are rapidly approaching the same condition. With waterwheel units, however, the situation is such that the capacity and speed ot the generator is often determined largely by the hydraulic conditions and the characteristics of the waterwheel which is to be used.

With steam engines the point of maximum efficiency is rather marked, as shown in the curve of Fig. 2, and the ratings are usually such that the engine is working under its most economical load at the rating of the electrical generator. With gas engines, however, the efficiency increases with the load beyond the capacity of the engine, as shown in Fig. 3, and for this reason the rating of the engine is generally made as nearly as possible to its maximum capacity, leaving a small margin for regulating purposes. With the steam turbine, Fig. 4, the efficiency curve is usually so flat that it is a question of desirable overload capacity which limits the rating of the turbine.

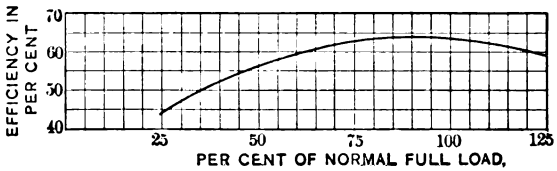

FIG. 2—PERFORMANCE CURVE OF 800 H.P. COMPOUND CONDENSING GAS ENGINE.

In the waterwheel unit, the efficiency usually falls off rapidly above and below the maximum point, so that the rating of the generator should correspond to the point of maximum efficiency of the water wheel. Steam engines and steam turbines are designed to operate with certain variations both in pressure of the steam and conditions of vacuum. Gas engines must accommodate themselves to variation in the quality of the gas.

With the waterwheels, however, by far the large majority of installations are subject to a change in head which varies over a wide percentage. In many of the low head installations the back water may bring about a change in head which is beyond the capacity of one wheel to accommodate, and in some plants additional wheels must be mounted on the same shaft and cut into service at times of low head. One particular instance of this kind is the plant of the Chattanooga and Tennessee River Power Company, where the head may vary from 20 to 42 ft. (6.1 to 12.8 m.). In most of the large developments this change in head is the limiting feature in the design of the water wheel as related to the generator capacity, for in all electrical work it is necessary that the speed of the generator be kept constant.

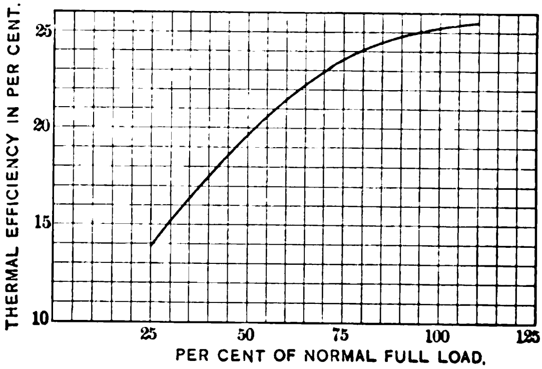

Fig. 3—Performance Curve of 2000-h.p. Gas Engine

Waterwheel runners of different designs are compared on the basis of their specific speeds. The specific speed of a waterwheel is the number of revolutions per minute at the point of maximum efficiency that a similar wheel will give when it delivers one horse power under one meter head. By comparison of the specific speeds we can judge of the characteristics of waterwheel runners without respect to their actual speed, power or head. A high specific speed means a high actual speed, and a low specific speed means a low actual speed in revolutions per minute. For this reason waterwheels with low specific speeds are generally used with high heads in order to make the speed of the generator within the range of good electrical design.

Waterwheels with high specific speeds have very deep runner vanes, and these are liable to erosion under high heads; also, the efficiency curves of high specific speed runners are more pointed than with the low specific speed type, and this allows a narrower margin for operation under the best conditions. This is clearly shown in curves in Fig. 5.

The maximum full load capacity of a turbine is that point beyond which the output decreases with an increase in gate opening. The margin between the point of maximum efficiency and of maximum capacity depends upon the specific speed of the runner, and is smaller the higher the specific speed. This is illustrated in Fig. 5, which shows that as the specific speed is increased the point at which maximum efficiency occurs approaches nearer to the power delivered at full gate opening. The specific speed may thus be increased to such an extent that the point of maximum efficiency and maximum output coincide. With low heads and high specific speeds it is therefore desirable to operate wheels near their point of maximum output, and to obtain the best results the generator should be designed giving consideration to this point.

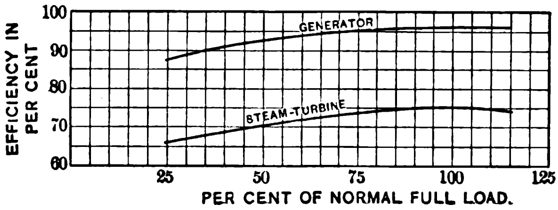

Fig. 4—Performance Curves of 5000-kv. Steam Turbo-Generator Set

Referring again to the curves in Fig. 5, it will be noted that the full load capacity occurs at about 6 per cent above normal or rated full load in all three cases. This is in accordance with the general practise, the margin being allowed for governing. It is also noted that for curves *B* and *C* the efficiency is falling off very rapidly at 6 per cent overload, and that should the gate be opened still further the output would reduce instead of increase. If with low specific speed wheels, as represented by curve *A*, the gates were still further opened, the power would continue to increase to some extent.

The point of maximum efficiency for wheels represented by curve *A* occurs at about 90 per cent of normal full load, in the case of *B* at 93.5 per cent, while in the case of *C* the maximum

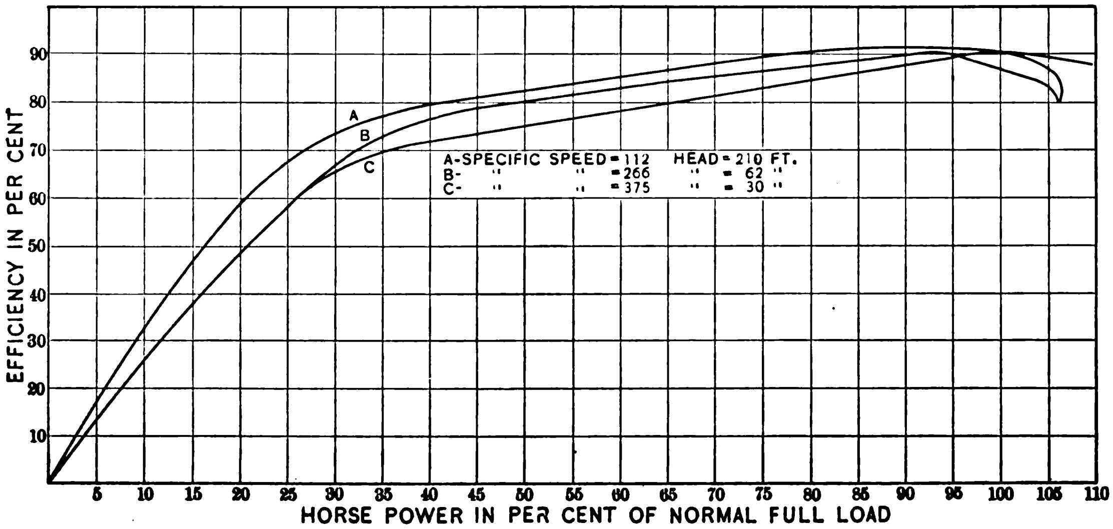

FIG. 5—PERFORMANCE CURVES OF SEVERAL TURBINES FOR VARIOUS HEADS AND SPECIFIC SPEEDS AS SHOWN

efficiency occurs just at the point of normal or rated full load. Thus, as stated before, the power at which the maximum efficiency occurs approaches nearer to full load as the specific speed increases.

With high head wheels, as represented by curve *A*, the efficiency remains very high over a very large range in power, while for low head wheels, curve *C*, the efficiency falls off rapidly as the power is reduced below the normal full load. For this reason it is desirable to run low head wheels under practically full load conditions. With high head wheels this is not so important, as the efficiency is still high at partial loads. With wheels as represented by curve *C*, it is also necessary to allow some margin above the normal full load for governing, as it is desirable to operate the turbine at its point of maximum efficiency With high head wheels, curve *A*, such a margin need not be allowed.

The curves plotted in Fig. 5 represent operating conditions under constant head. This, however, is not always realized, especially in low head plants where floods and dry seasons sometimes cause quite a variation in the head, and this has, as previously mentioned, quite a bearing on the selection of the waterwheel, and should therefore be given careful consideration.

If the speed of the unit could be allowed to vary at all times as the square root of the ratio of the heads the shape of the performance curve for any head other than normal would be the same as that secured at normal head, but the output would vary as the 3/2 power of the ratio of the heads. In the case of wheels driving alternating-current generators a speed variation is not permissible and the speed must be kept constant irrespective of any variation in head which may occur.

In Fig. 6 is plotted a set of curves illustrating the effect of a varying head. A 10,000-h.p. turbine is assumed to operate normally under a 32-ft. (9.75-m.) head, the speed to be constant for a range of heads from 26 to 38 ft. (7.92 to 11.6 m.). As the head goes up to 38 ft. (11.6 m.) the shape of the curve approaches more closely curve *B* in Fig. 5, while when the head falls to 26 ft. (7.92 m.), the speed being constant, it approaches more closely to curve *C*. In other words, when operating under a 38-ft. (11.6-m.) head, the speed is lower than the best speed for the runner under that head, while when operating under the 26-ft. (7.92-m.) head, the speed of the wheel is higher than the best speed. Under 38 ft. (11.6 m.) head the point of maximum

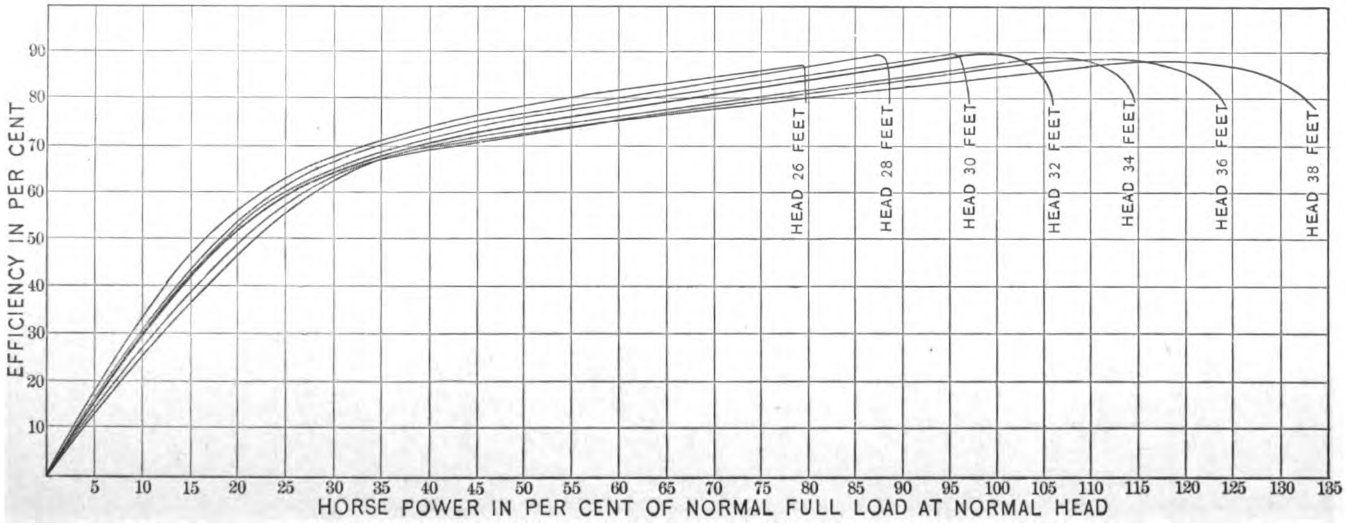

FIG. 6—10,000 H.P. TURBINE-CURVES SHOWING EFFICIENCY AND POWER FOR CONSTANT SPEED AND A NORMAL HEAD OF 32 FT. FOR VARIOUS HEADS AS SHOWN

efficiency is, furthermore, considerably below the normal full load at that head, while under 26 ft. (7.92 m.) head the power at which maximum efficiency occurs is the actual full load, illustrating the points discussed above in reference to the relation of the power at which maximum efficiency occurs and the normal full load power for various specific speeds.

Let us assume that a selection of a wheel is to be made for an installation, and that performance curves are desired, showing the expected efficiency for various loads and speeds. Curves *A*, *B* and *C* in Fig. 5 may each represent a possible curve, dependent upon the revolutions selected for the turbine in question, the revolutions being directly proportional to the specific speeds, and they will illustrate the manner in which the efficiencies at partial gate openings will fall off in any one case, depending upon the actual revolutions per minute selected for the design of the wheel. They will also give an idea as to the margin between the normal full load and the power at which the point of maximum efficiency will occur. In the selection of a speed for any installation, therefore, aside from the cost of the generators, the question of the wheel efficiencies at partial gate openings has a considerable bearing. Where a unit is likely to operate under a very wide range in power, it would be advisable to select a wheel represented by curve *A*, giving a high efficiency for a considerable range in power.

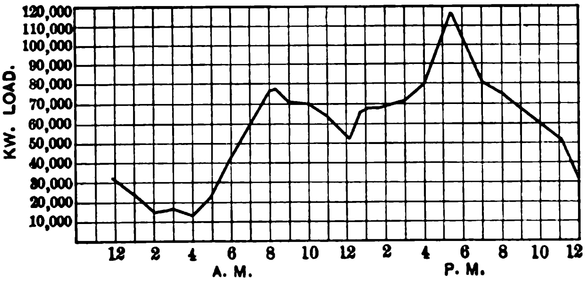

FIG. 7—TYPICAL LOAD CURVE OF LARGE CENTRAL STATION—DECEMBER LOAD

All power systems have a more or less varying load, and this has a very important bearing on the selection of the proper generating equipment and on the economy of the plant. The load will vary considerably, not only during the 24 hours of the day but also for different periods during the year. The load curve also differs materially for different kinds of load, such as for central stations, industrial establishments, street railways, etc.; a typical load curve of a central station is represented in Fig. 7.

The size and capacity of the units in a hydroelectric station is determined, in many cases, quite largely by the hydraulic conditions. In operating, the number should, wherever possible, never be less than four, unless the station forms part of a larger system. It is better to operate machines as near full load as possible, and to start new units instead of utilizing overload capacities. Where sudden overloads of considerable magnitude come on the system for very short periods it is, of course, necessary to have a wheel capacity sufficient to care for them.

The foregoing discussion indicates that waterwheel characteristics will vary with different installations. For the sake of standardization it is desirable to give the generators a maximum rating at a certain temperature. The proper relation of the capacities of generator and waterwheel should be considered for each installation.

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THE APPLICATION OF SYNCHRONOUS MOTORS TO A WATER POWER TRANSMISSION SYSTEM FOR THE BETTERMENT OF SERVICE STANDARDS

BY LUCIUS B. ANDRUS

The writer will in this paper trace the history, to some extent, of the causes leading up to the application of synchronous apparatus to the water power transmission system of the Indiana and Michigan Electric Company for the purpose of maintaining adequate and serviceable standards comparable with such as would be realized with an individual steam plant situated where power and light are to be utilized.

The paper is prepared primarily from an operating standpoint and only such mathematics is used as is necessary in explaining results attained, and to furnish such a guide as would prevent attempts at the impossible.

The growth of human industry depends on nothing more than upon the possession of cheap and convenient power. Labor is by far the largest factor in the cost of many manufactured articles and in so far as motive power is cheap and easy of application, it tends to displace the strength of human hands in all manufacturing processes and so to reduce the labor cost and to set free that labor for other and less purely machine-like purposes.

Therefore industrial operations have steadily gravitated toward regions where power is easily procured, often at the sacrifice of certain other advantages. This is in no wise better shown than by the growth of cities around easily available water powers, even in regions where both raw material and finished product were subject to considerable cost of transportation. With the introduction of the steam engine came a corresponding tendency to gather factories about regions of cheap fuel. These localities, like those in which water power is plentiful, seldom coincide with centers of cheap material and transportation, so that it has generally been desirable to strike an average condition of maximum economy by transporting the necessary power, stored in the form of fuel, to some advantageous point.

Experience has shown, however, that while the hauling of coal is a simple and comparatively cheap expedient, fuel utilized for running heat engines is in very many cases sufficiently more expensive than hydraulic power to be out of competition in cases where the latter can be transmitted with a reasonable degree of economy to places that are favorable for its utilization. And in general it is found that there is a field for the transmission of power obtained from water heads in competition with power obtained from some other source, such as coal.

The sources of energy on which we may draw for power to be employed in any particular locality, or to be transmitted elsewhere, are not very diversified. Only two play any important part in our immediate industrial economy, coal, and water power. The supply of coal is hard to estimate. Coal is now found quite plentifully over the country as a whole, although its heat value varies greatly, and exploration in both old coal fields and new coal fields is constantly bringing to light new sources. Many computations concerning the probable duration of the coal supply have been made, but the conclusions reached are, in a certain degree, unreliable, owing to the great probability that only a very small proportion of the available coal is as yet uncovered. Certain it is that for at least the next few years the scarcity of coal, due to an exhaustion of the sources, need not worry us; still it is altogether probable that the price of coal will be gradually increased, owing to the increased difficulty in working some of the older mines, and also due to the fact that the supply now uncovered and being consumed at the present rate of increase indicates that the supply of anthracite coal will be exhausted in fifty years and the supply of bituminous coal in two hundred years.

Water power derived from streams, and which can be relied upon as a continuous source of power, is not distributed with the same impartiality as fuel, but, nevertheless, exists in many regions in sufficient amount to be of importance in industrial operations, providing that the same results can be obtained from either source at the same cost.

Water power is by no means always cheaper than power from fuel, but as a general rule, water powers are not developed unless the water power is cheaper than power from fuel, by such an amount that it can be transformed into electrical energy and transmitted to at least a moderate distance without losing its economic advantage, and where such is the case, water power is largely used for general distribution. Referring to the previous statement relative to the increase in price of fuel, water powers which at the present time show no great economic advantage over steam power, will in the future be valuable assets in proportion to the increase in price of fuel.

Water powers, however, as a general rule, are located some distance from the load centers. Often the locations which are favorable for the development of a water power are not favorable for its utilization. In general, it is found that there is a field for the transmission of power which has been developed in water power plants, and we can assume that all the electrical energy to be transmitted, with the exception of that used for lights, will be used by motors, either industrial or street railway. This statement must be qualified, however; that is, the service to be supplied over the transmission lines and to be used for lighting, industrial power and railway power must at least equal such adequate and serviceable standards pertaining to the supply of electrical energy as would be realized from the individual steam plant situated where the power is to be utilized. If such standards can be maintained, it is fair to assume that purchased electric power will be given preference over individual steam plants burning coal, for the reason that the electric motor as a prime mover has a great advantage over individual engine-driven industrial plants. No coal and water is required to be furnished to it and no ashes and smoke comes out from it, and the resulting cleanliness in industrial establishments has its effect in raising the efficiency of the men, from a manufacturing standpoint, everything else being equal.

The manufacturer, as a rule, where he can purchase both light and power as cheaply as he can make them himself, prefers to purchase power and keep his investment in machinery down to a minimum, for the reason that the same amount of money which would be required to build an industrial plant, if invested in the manufacturer's business, will yield him greater returns upon the investment. There are some exceptions, however, to this rule, one of which is where the process of manufacture requires a great deal of steam. In such an industry it is at times more economical for the manufacturer to put in his own plant.

Referring to the previous statement that the service to be supplied from the water power plants over the transmission lines and to be used for lighting, industrial power and railway power must at least equal such adequate and servicable standards pertaining to the supply of electrical energy as would be realized from the individual steam plant situated where the power is to be utilized, the first qualification refers to lighting.

To enter into the field for incandescent lighting, the refinements necessary for producing a fairly constant incandescent light must be considered. Fluctuations in the brightness of a light are annoying and tend to create dissatisfaction among consumers. Therefore, it is necessary to get close voltage regulation.

The test for regulation in a dynamo consists in determining its change in voltage under different loads, or output of current *the speed being maintained constant.*

With the speed being maintained constant and with constant separate excitation and with a non-inductive load, the companies manufacturing alternators would make gurantees stating that the load may be varied from normal rated current to no-load current and the voltage will rise approximately ten per cent. Since, however, the generators were never subjected to such extreme variations under normal operating conditions, the voltage regulation was usually kept within a range of four or five per cent, corrected for a constant speed; however, it was impossible to hold constant speed under load variations, therefore the changes in generator voltage due to load fluctuations were due to two causes: the inherent regulation of the generator itself, and the further change due to the fact that the speed would drop due to an additional load, and that the speed would rise due to decrease in load. Therefore a voltage variation of, say, five per cent, as a result of speed variation of a similar amount, would produce a much larger variation in the candle power of an incandescent light, for the following reason:

The alternating current must pass through zero values in reversing its direction, and the length of the period during which there is no appreciable current flowing, due to this passing through the zero value, gets longer as the speed, and consequently the frequency, gets lower. The light of the incandescent lamp is made up of the visible octaves of heat waves, and the heating of the filament which produces the heat waves is caused by the electric current flowing through the filament. Consequently when the current is going through a zero value, the filament gives up its heat, which results in a dimming in the light, with a lower frequency, or, which is the same thing, with any drop in speed, when the effect is more noticeable. A drop in speed also causes a drop in voltage, which gives a drop in pressure across the lamp terminals due to inherent drop in voltage of generator with increased load and due to drop in voltage from drop in speed, and consequently a less amount of current flows through the lamp filament, which causes a less amount of heat and necessarily results in a dimming of the light. Consequently the drop in speed is doubly detrimental and the inherent drop in voltage is also detrimental to the constancy of light as considered here.

The foregoing analysis of the conditions in the water power plant which would tend to give unsatisfactory service for incandescent lighting, shows there are two factors to better if possible, first, the changes in voltage due to inherent electrical characteristics of the generators and transmission lines, and second, the changes in speed due to the increase or decrease of load, and the consequent change in the frequency, resulting in a difference in the intensity of the light, due to the low heat inertia of the lamp filament.

It is apparent that the second factor can be bettered by maintaining a speed as nearly constant as it is possible to get. Therefore, attention was first given to an analysis of the speed conditions.

The work which a body can do by virtue of its motion or the work required to bring a body to rest is a measure of its kinetic energy.

The work is measured in foot-pounds, Considering a body starting from rest, it will, under the influence of gravity at the earth's surface, have a velocity of 32.2 ft. at end of first second.

$$g = 32.2$$

Since the initial velocity was 0 and the velocity at the end of first second was g, the average or mean velocity was $\frac{g}{2}$

$$\text{The work in ft-lb.} = \text{weight} \times \frac{g}{2} \qquad (1)$$

Since the rate of work involves time, and since the time

$= \dfrac{V}{g}$, and since V during the first second $= g$, therefore

$\dfrac{V}{g} = 1$ and

$$\text{work in ft-lb.} = \text{weight} \times \frac{g}{2} \times 1 \qquad \textbf{(2)}$$

Now by doubling the velocity, or making $V = 2g$, we make the mean velocity $\dfrac{2\,g}{2} = g$ and the time $\dfrac{2\,g}{g} = 2$, thus equation (**2**) becomes

$$\text{Work in ft-lb.} = \text{weight} \times g \times 2, \qquad \textbf{(3)}$$

which is four times equation (**2**), thus, in general, work is proportional to $\left(\dfrac{V}{g}\right)^2$, everything else being equal.

In general, total work in ft-lb.

$$= \text{weight of moving body} \times \frac{g}{2} \times \left(\frac{V}{g}\right)^2$$

$$= \text{weight ot moving body} \times \frac{V^2}{2\,g} \qquad \textbf{(4)}$$

In equation (**4**) the left-hand side represents the work in any given case and the right-hand side represents the kinetic energy of the body by which it is enabled to do said work.

Let us apply equation (**4**) to regulation of water power plants with the following notation:

E = kinetic energy necessary to be stored in flywheel effect.
M = mass
V_1 = angular velocity at normal speed of turbine
V_2 = angular velocity after a sudden load variation
W = weight of revolving elements of the units
R = radius of gyration of revolving elements
$\overline{HP}$ = horse power of load variation
$\overline{RPM}$ = revolutions per minute
$\overline{T}$ = time in seconds for full gate opening or closing.
$\overline{\%S}$ = percentage of speed regulation.
(One $\overline{HP}$ = 550 ft-lb. per second).

The left-hand side of equation (**4**) will equal the average of 0 and $550 \times T \times \overline{HP}$,

$$\frac{550 \times T \times \overline{HP}}{2} \qquad (\mathbf{5})$$

The right-hand side will show the kinetic energy given up or absorbed during change in speed and will equal

$$E = \frac{M V^2}{2}$$

$$= \frac{W V^2}{2 g}$$

$$= \frac{W}{2 g} (V_2^2 - V_1^2) \qquad (\mathbf{6})$$

Since $V_2 = V_1 [1 - \overline{\% S}]$, substituting this expression in equation (**6**),

$$\text{for } V_2 \, E = \frac{W}{2 g} \{ (V_1 [1 - \overline{\% S}\,])^2 - V_1^2 \} \qquad (\mathbf{7})$$

Expanding the quantity in parentheses,

$$V_1^2 - 2 \, \overline{\% S} \, V_1^2 + \overline{\% S}^2 \, V_1^2$$

Combining the quantities in the brackets,

$$V_1^2 - 2 \, \overline{\% S} \, V_1^2 + \overline{\% S}^2 \, V_1^2 - V_1^2$$

Factoring out V_1^2,

$$V_1^2 (\overline{\% S} - 2 \, \overline{\% S})$$

Neglecting $\overline{\% S}^2$ as negligible compared with $\overline{\% S}$ and considering the negative sign as indicative of a drop in speed and not having any numerical significance, it can be dropped and equation (**7**) becomes

$$E = \frac{W}{2 g} \, 2 \, \overline{\% S} \, V_1^2 \qquad (\mathbf{8})$$

Since V_1 in equation (**8**) is in terms of straight-line velocity, it will be necessary to reduce it to linear velocity at the distance R from center of revolving elements.

$$\text{Linear velocity per second} = \frac{2 \pi \times R \times \overline{RPM}}{60}$$

Substituting this value for V_1 in equation (**8**),

$$E = \frac{W}{2\,g}\, 2\, \overline{\%\,S}\, \frac{4\,\pi^2\, R^2\, \overline{R\,P\,M}^2}{3600} \tag{9}$$

Equating equation (**5**) and equation (**9**),

$$\frac{550 \times T \times \overline{H\,P}}{2} = \frac{W}{2\,g}\, 2\, \overline{\%\,S}\, \frac{4\,\pi^2\, R^2\, \overline{R\,P\,M}^2}{3600}$$

Transposing, simplyfying and combining,

$$\overline{\%\,S} = \frac{800{,}000 \times T \times \overline{H\,P}}{W\,R^2 \times \overline{R\,P\,M}^2} \tag{10}$$

With the governors installed in one of the Indiana and Michigan Electric Company's plants, the time of operation of the governors through the range required to accommodate the load changes was found to be about two seconds, and the maximum horse power variation of the load was found to be about 300. The flywheel effect of the generators, as given by the manufacturing company, was the equivalent of 800,000 lb. at one-ft. radius, and the generator speed as fixed by the available operating head of the water was 120 rev. per. min, and for simplicity using 288 h.p. as load variation and substituting the numerical values in equation (**10**) we get

$$\overline{\%\,S} = \frac{800{,}000 \times 2 \times 288}{800{,}000 \times 3600}$$

$$= 0.16, \text{ or } 16 \text{ per cent.}$$

This means that with a 288-h.p. change in load, and with the aforesaid conditions, we will get a 16 per cent variation in speed if the load is thrown on or off of one generator.

Assuming a 288-h.p. load thrown on a generator, we would get a 16 per cent drop in speed. Referring to a previous statement in this paper, a drop in speed would produce a much larger variation in the candle power of a lamp than would be caused by the drop in speed alone, due to the additional inherent regulation drop in the generator and the lowering of the frequency. A brief study of equation (**10**) is then in order to see just what factors can be varied in order to produce a betterment of the regulation. As a general statement, we can say that if any factor in the numerator can be decreased or any factor in the denominator can be increased, the regulation will be bettered. Each factor was fixed by the design of the apparatus purchased, with the exception of *H P* appearing in the numerator, which refers to the load thrown on or off.

Under our assumed condition, we have a load variation of 288 h.p. Assuming that each generator had a full-load capacity, of 1200 h.p. and that one generator only was running, the additional load of 288 h.p. would cause a drop in speed of 16 per cent when thrown on the one generator. However, if the total load on the plant was sufficiently heavy to require three generators to be running, the additional 288 h.p. thrown on would be divided among the three generators, making an additional load of 96 h.p. on each generator. Applying equation (**10**), this would mean a speed drop of approximately

$$\overline{\%\, S} = \frac{800{,}000 \times 1 \times 96}{800{,}000 \times 3600}$$

$$= 0.026, \text{ or } 2.6 \text{ per cent.}$$

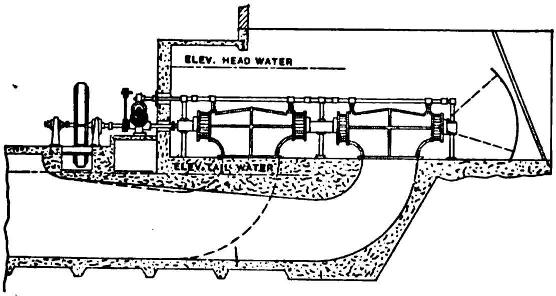

FIG. 1

I think, then, that two conclusions may be drawn from the previous statements with reference to the horse power variation of load. In each of the examples given, 288 h.p. was thrown on the generators. In the first case, with a total load requiring one generator to be in operation, the speed drop was 16 per cent. In the second case, with a total load requiring three generators to be in operation, the speed drop was 2.6 per cent. This means that good speed regulation is dependent on the ratio of the total variations to the total load in water power plants using turbine wheels set in an open penstock, which is the standard arrangement of the Indiana and Michigan Electric Company. (See Fig. 1). It is apparent that as the total load on the plant increases, the regulation is going to be bettered, for the reason that the variations do not increase with the load. In a previous statement with reference to the factors entering into equation (**10**), it was said that if the load on the plant is increased and if this increase in load increases any factor appearing in the denominator of equation (**10**), the additional load will apply to further betterment of the speed regulation. There are two factors in the denominator, $W R^2$ and $\overline{R P M}^2$. The constant frequency requires that the rev. per min. be not increased. With reference to the factor $W R^2$, which we will term flywheel effect, it is fixed by the weight of the revolving element of the generator and of the water wheel. However, if the additional increase in total load under discussion is to be added to the plant and will be driven by synchronous motors or induction motors, which are essentially synchronous machines and will keep in step with the generator, the conditions will be conducive to steady speed, for though variations of load produced by street railways using synchronous converters or motor-generator sets, and factory loads using synchronous or induction motors, may tend to be large and rapid, no change in speed can occur withour changing the speed of every generator, motor and every piece of machinery operating on the system. In addition to this great total inertia or flywheel effect, every change in speed of machinery is accompanied by a corresponding change in load, which is another factor tending to constancy of speed, and when operating with all the load electrically interconnected, the inertia, or flywheel effect, of the moving parts is the inertia or flywheel effect of the whole system. Therefore, an additional motor or railway load is doubly beneficial to the regulation of the water power plant. It increases the total load, thus reducing the ratio of the total variations to the total load, and it also increases the inertia or flywheel effect of the system as a whole. So that one practical solution of the problem of speed regulation lies in the direction of increasing the amount of power to be delivered from the system, until the variations caused by the governors bear a small ratio to the total load.

With reference to the conclusions drawn from the preceding paragraphs, it is apparent that to get the benefit of the flywheel effect of the whole load it must be a motor load or street railway load, or the equivalent, in that the auxiliary apparatus must be essentially synchronous apparatus. Now, considering a lighting load, the same argument applies with reference to the horse power of the additional lighting load being added, which will decrease the ratio of the variations in horse power to the total load in horse power, and is beneficial to that extent. But the addition of the lighting load is not doubly beneficial as was the increase in power load, for the reason that it does not add to the flywheel effect of the system. Therefore, we will have to resort to some other means of increasing the flywheel effect during the lighting load when it is the desire to have the best of speed regulation consistent with the cost entailed. The flywheel effect of generators, as a rule, cannot be increased after the generators are once built, without changing the design of the revolving element; that is, it will require larger bearings, larger shaft, etc. for a greater weight of revolving element, to get any additional flywheel effect. However, if a piece of auxiliary apparatus could be electrically interconnected to the generators so as to be always in step with them, and if this auxiliary piece of apparatus be designed to secure the desired flywheel effect at a reasonable cost, it would be a valuable adjunct to the electrical system from a speed regulation standpoint. The synchronous motor with great flywheel effect, either built in the revolving element or secured by driving a flywheel for the purpose, furnishes such a piece of apparatus, and it was this line of thought which suggested to the writer the use of the synchronous motor on transmission systems; that is, I conceived of it as a valuable adjunct, when properly designed, to secure better speed regulation on the water power system, with the advantage of being able to locate it at some convenient point. This point was to be chosen where the motor could be used to drive some piece of apparatus doing useful work, or used as a generator in case of emergency, to help offset what was regarded, at the time under consideration, as a considerable expenditure for what might be termed experimental purposes.

As previously stated, the localities in which suitable locations for water-power development occur seldom coincide with the load centers, or centers of cheap material and transportation, so that it has generally been found desirable to transmit the necessary power in the form of electrical energy to some advantageous point for its use. South Bend and Elkhart are two such load-center locations with reference to the transmission system of the Indiana and Michigan Electric Company, the electrical power for which is supplied from the water power developments at Buchanan and Twin Branch (see Fig. 2). Two old generators were used as synchronous motors to drive line shafts with many pulleys belted to d-c. arc machines used for street lighting, thus adding to the inertia or flywheel effect of the system during the lighting period, bettering the speed regulation at a time when better speed regulation was valuable.

The transmission line by which the electrical interconnection between the plants and the load centers referred to is accomplished, crossing the country, introduces the possibility of providing rural and suburban service, both industrial and railway, that could not be profitably reached by any local central station situated in a city.

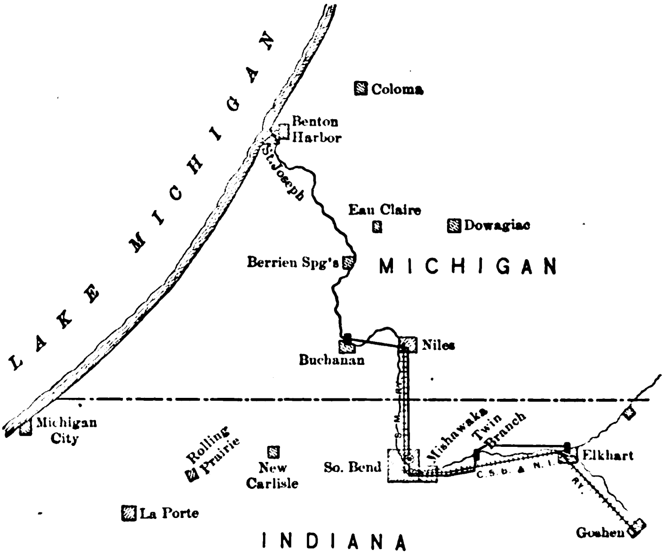

FIG. 2—TRANSMISSION SYSTEM INDIANA AND MICHIGAN ELECTRIC CO., 1904

However, in order to maintain such standards for service as before referred to in this paper, it was apparent that if a constant voltage were to be maintained at South Bend, the busbar voltage at the generating station must be raised and lowered through such a range between full load and light load conditions at South Bend that it would necessarily make the service connected directly to the water power plant very poor from a voltage regulation standpoint, and this fact was also true with reference to the voltage regulation which would be maintained at Elkhart. However, since synchronous motors were to be used at both South Bend and Elkhart to better the speed regulation, the electrical characteristics of the synchronous motors were investigated with reference to their voltage regulation properties.

For any given load on a synchronous motor, the armature current is at a minimum for a certain critical value of field excitation. At this point the motor constitutes a load of unity power factor, the current taken by the motor being neither lagging nor leading. For weaker field excitations, the current taken by the motor is lagging and establishes an artificial drop in the line, which is the condition which we wish to prevail under light load conditions on the transmission line, and for stronger field excitation the current taken is leading (see Fig. 3), and while adding to the full-load current, the leading current will overcome the drop due to the load itself, with a proper amount of reactance, etc., in the circuit. Therefore, controlling the excitation of the synchronous motor is a means of varying the power factor of the transmission circuits with either a lagging wattless current, no wattless current, or a leading wattless current.

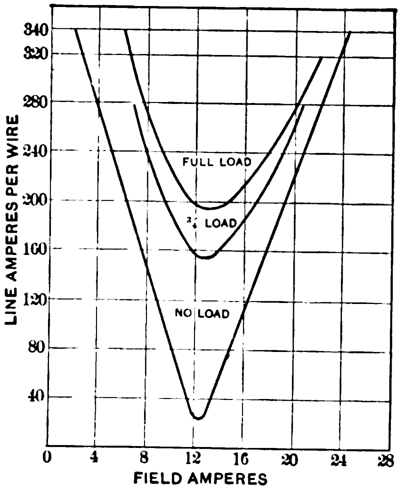

FIG. 3—CURRENT CHARACTERISTICS OF A SYNCHRONOUS MOTOR

The fact of the lagging current taken by the motor to establish an artificial drop under light load conditions, and of the leading current taken by the motor to overcome the load drop under full load conditions, and the fact that the motor runs at unity power factor at about half load, having no effect on the line characteristics, justify the following conclusions: that if the motor excitation be adjusted for unity power factor at the half-load line condition, the difference between the generator busbar voltage and the substation busbar voltage will be the line drop under the half-load conditions, and that at any load less than half load, with constant generator voltage and proper motor field excitation, the current taken by the motor will be lagging and will establish an artificial drop in the line, and at any load greater than half load, with proper motor field excitation, the current taken by the motor will be leading and will overcome the line drop. Therefore, with proper synchronous motor electrical characteristics, it is apparent that the generator voltage and the substation voltage can both remain constant and have a fixed ratio, one to the other, equal to the line drop at half load. Thus, a synchronous motor fills another essential requirement, that the control of the voltage regulation and the allowing of a constant voltage be carried out at both the generating station and the substations, which is a necessary condition in maintaining the adequate standards for service to which reference has been made.

At the time at which the synchronous " condenser " had been tried out and made use of for the purposes described in the previous paragraphs of this paper, attention was called to a form of automatic voltage regulator which was being developed, and the fact that with a properly designed synchronous motor we would be able to maintain a flat voltage at both the generating-station and the substation suggested that it might be possible to make the voltage control not only constant and with a fixed ratio of generator voltage to substation voltage, but that we might make this condition entirely automatic by using an automatic voltage regulator in the field circuit of both the synchronous motor and the generators. It was apparent that if this were a successful expedient, our standards of service would be raised to a higher degree.

One of the earlier types of automatic voltage regulators was purchased and the experiment worked out to our satisfaction, but it was apparent that with somewhat different electrical characteristics of the synchronous motor we could get better results, and a new synchronous motor designed with reference to the service intended was installed together with a later type of automatic voltage regulator. How successful we were in the matter of voltage regulation is shown by the chart (see Fig. 4), the better voltage regulation being secured as a result of both better speed regulation and voltage control due to the use of the synchronous motor.

Reviewing the electrical characteristics of other auxiliary apparatus to be used on the system, we may say that all systems of electrical transmission of power make use of alternating current for this purpose. The alternating current differs from the direct current in that the current flowing in a circuit upon which an alternating e.m.f. is impressed may have any phase relation with respect to the impressed e.m. f. depending upon the nature of the transmission line, feeder circuits and the apparatus taking current from the latter.

Induction motors, transformers and arc-lighting apparatus take a certain amount of exciting current which lags behind the impressed e.m.f. Condensers and cables, and sometimes long transmission lines, take a certain amount of charging current which leads the impressed e.m.f. The synchronous motor has the well known property of taking current from the line, which may have any desired phase relation with respect to the impressed e.m.f., depending only upon the strength of the field, which is excited from a separate direct-current source.

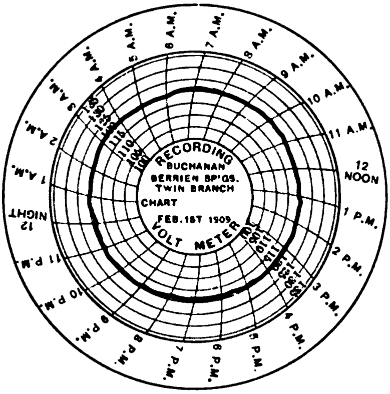

FIG. 4

If a substation requires a certain number of foot-pounds of energy per minute (or electrical horse power) for distribution to furnish power and light, assuming factory machinery to be driven by induction motors, the substation equipment and transmission lines should be so designed as to furnish this power and light with an investment of the least possible amount of capital, and with the expenditure of the least amount of electrical energy as losses in producing it, consistent with maintaining an adequate and serviceable standard comparable with such as would be realized with an individual steam plant situated where the power and light are to be utilized.

Two foregoing statements, first, " the transmission line by which the electrical interconnection is accomplished, crossing the country,. introduces the possibility of providing rural and suburban service, both industrial and railway," and second, " consistent with maintaining an adeqaute and serviceable standard comparable with such as would be realized with an individual steam plant situated where the power and light are to be utilized," bring us back the subject proper of this paper—the application of synchronous apparatus to transmission systems for the purpose of maintaining adequate and serviceable standards comparable with such as would be realized with an individual steam plant situated where power and light are to be utilized.

The matter of maintaining adequate and serviceable standards calls for a small allowable variation in voltage, and the fact that rural and suburban service is to be supplied along the entire line requires that the voltage variation at the generator proper, and at any point along the transmission line where it may be tapped for service, be kept approximately as uniform as the voltage at the receiving end of the line. Throughout this paper the reactance will be considered as having a constant value, the frequency and speed remaining constant, hence the reactance drop will be proportional to the value of the current, the reactance including both the line and transformers. The problem then resolves itself into one of keeping a comparatively steady ampere load over the line by introducing a lagging current for the light load conditions, this lagging ampere load to establish an artificial drop, when otherwise there would be none—the drop to be approximately the same as that, we will say, under half-load conditions, when there is no wattless ampere load being introduced; and at full load some function should be performed to help overcome the drop due to the full load proper. This is fulfilled by the ntroduction of leading current by the motor. The synchronous motor or converter has the characteristics necessary to perform the required functions.

For the purpose of a numerical instance, it will be assumed that in this case the synchronous motor is placed in a substation 20 miles (32.2 km.) from the generating station, and the generating tation, and substation are connected by a transmission line.

It is the object of this paper to point out some of the advantages of the application of synchronous apparatus to transmission systems, and to preface that part of the paper which has to do with quantitative electrical results, a numerical instance will be taken, showing the required variation of voltage at the generating station in order to maintain a constant voltage at the substation, both with and without any synchronous apparatus being operated at the substation. The load will be assumed to be a day load, made up mostly of induction motors, with an inherent power factor of 75 per cent.

It is desirable at this point to recapitulate some of the fundamental principles involved in any electric power transmission problem.

The general equation giving the relation between voltage, current and line constants is as follows:

$$\text{generator volts} = \text{substation volts} + \text{line drop} \qquad \textbf{(11)}$$

The current is the amperes in each line conductor. The amperes in each conductor equal (energy current) + (difference between lagging and leading current) vectorially added, that is, the wattless, currents are displaced 90 deg. from the energy current.

In order to solve the equations by the ordinary rule of algebra, the wattless current will be assumed to be multiplied by $\sqrt{-1}$.

Multiplying a vector -1 turns it through 180 deg. counterclockwise. Since it is desired to turn the vector representing wattless current through 90 deg. only, the vector should be multiplied by such a quantity that when once performed will equal 90 deg. and which twice performed will equal 180 deg. and also when twice performed will equal -1.

Such a quantity will be $\sqrt{1}$.

$$j = \sqrt{-1}$$

The line current can then be stated as follows:

$$C_{en} + j\,C_{la} - j\,C_{le}$$

$$C = \text{current}$$

Line drop will equal current × impedance at 60 deg. lag.

Since the drop can be resolved into two components, a drop across resistance and a drop across reactance, the impedance can be stated as follows:

$$R - j\,X$$

where R = resistance per phase,
and X = reactance per phase including transformers, line and added reactance.

Line drop can then be stated

$$(C_{en} + j\,C_{la} - j\,C_{le})\,(R - j\,X)$$

As previously stated in this paper, the matter of maintaining adequate and serviceable standards calls for a small allowable variation in voltage, and the fact that rural suburban service is to be supplied along the entire line requires that the voltage variation at the generator proper, and at any point along the transmission line where the line may be tapped for service, be kept approximately as uniform as the voltage at the receiving end of the line.

This statement can be set forth in the form of a ratio

$$\frac{V_G}{V_S} = K \tag{12}$$

where K is a constant,
V_G = generator volts,
and V_S = substation volts.

Stating the general equation (**11**) algebraically,

$$V_G = V_S + [\underbrace{(C_{en} + j\,C_{la} - j\,C_{le})\,(R - j\,X)}_{\text{line drop}}]$$

Expanding,

$$V_G = V_S + [\overbrace{C_{en}\,R - C_{en}\,j\,X + j\,C_{la}\,R + C_{la}\,X - i\,C_{le}\,R - C_{la}\,X}^{\text{line drop}}]$$

Each quantity having a coefficient is imaginary. Separating out the imaginary quantities,

$$V_G = V_S + C_{en}\,R + (C_{la} - C_{le})\,X - j\,(C_{en}\,X - C_{la}\,R + C_{le}\,R)$$

The imaginary quantity is small as compared with the real, and can be neglected, and the equation then becomes

$$V_G \doteq V_S + [(C_{en}\,R) + (C_{la} - C_{le})\,X] \tag{13}$$

Giving finite value to line drop equation at this point, to show the general effect of increasing leading current,

$C_{en} + (C_{la} - C_{le})\,X$
$5 + (1 - 1)\,2 = 5$ volts line drop
$5 + (1 - 2)\,2 = 3$ " " "

This shows that an increase of leading current has the effect of decreasing the line drop, and increasing lagging current has the effect of increasing line drop.

Since the leading current is to be supplied by the synchronous motor, we can get its value from equation (**13**) as follows:

$$C_{le} = \frac{V_S - V_G + C_{en} R + C_{la} X}{X} \tag{14}$$

From the ratio $\frac{V_G}{V} = K$ we get

$$V_G = K V_S$$

Substituting for V_G in equation (**14**) to get the leading current in terms of substation voltage,

$$C_{le} = \frac{V_S (1 - K) + C_{en} R + C_{la} X}{X} \tag{15}$$

As previously stated, the problem is to keep $\frac{V_G}{V_S}$ constant at all loads.

It results from this condition, that at light load or no load on the receiving circuit, a lagging current has to be taken by the synchronous motor to establish an artificial drop, when otherwise there would be none, and at full load a leading current should be taken to help to overcome the drop due to load proper.

We can derive a value for the constant K from equation (**15**).

$$K = \frac{V_S + C_{en} R + C_{la} X - C_{le} X}{V_S} \tag{16}$$

Equations (**15**) and (**16**) give a means of determining the amount of wattless current necessary to maintain the ratio K between generator voltage V_G and substation voltage V_S over a transmission line with constants R and X, which constants can be taken from any electrical engineers' handbook. (Foster's Handbook, page 281.)

Assuming that the synchronous motor is to be used to its rated capacity, the motor should give full lagging current at no load on the line to establish the artificial drop, and should give full leading current at full load on the line to overcome the drop due to the full load proper.

All leading current must be supplied by the synchronous motor, therefore C_m will be used to denote the full load current per leg in the motor and will be equal to $- C_{le}$ as given in the line equations.

For a no-load condition on the line

$C_{en} = 0$

$C_{la} = 0$

$C_m = C_{le}$

These values substituted in the line equations will determine the full leading current on the motor to give full lagging current on the line to establish an artificial drop.

Substituting these values in equation (**16**),

$$K = \frac{V_S + O\,R + O\,X - (-C_m)\,X}{V_S}$$

$$= \frac{V_S + C_m X}{V_S}$$

Substituting this value of K in equation (**15**),

$$-C_m = \frac{\left[V_S\left(1 - \frac{V_S + C_m X}{V_S}\right)\right] + C_{en} R + C_{la} X}{X}$$

$$-C_m X = (C_m X) + C_{en} R + C_{la} X$$

$$-2\,C_m X = C_{en} R + C_{la} X$$

$$-C_m = \frac{C_{en} R + C_{la} X}{2\,X} \qquad \textbf{(17)}$$

Equation (**17**) determines the maximum rating of the synchronous motor.

In order to determine how much higher the generator voltage (V_G) should be kept than the voltage at substation (V_S), substitute the value of $(-C_m)$ in equation (**17**) for (C_{le}) in equation (**16**).

$$K = \frac{V_S + C_{en} R + C_{la} X - \left(\frac{C_{en} R + C_{la} X}{2\,X}\right)X}{V_S}$$

$$K = \frac{2\,V_S + 2\,C_{en} R + 2\,C_{la} X - C_{en} R - C_{la} X}{2\,V_S}$$

$$K = 1 + \frac{C_{en} R + C_{la} X}{2\,V_S} \qquad \textbf{(18)}$$

Equation (**18**) gives the ratio of voltages at all loads between generator and substation end of line.

Numerical Example. 20 miles (32.187 km.) length of line; 1000 kw. delivered; 13,200 volts delivered; 60-cycle; three-phase; No. 2 B. & S. gage copper on 24-in. (61-cm.) centers; 75 per cent power factor.

R = 16.5 ohms
X = 13.3 ohms

$$C_{en} = \frac{1{,}000{,}000}{13{,}200 \times 1.73} = 43.7 \text{ amperes per leg.}$$

$$C_{la} = \sqrt{\left(\frac{43.7}{0.75}\right)^2 - (43.7)^2}$$

$$= 38.6 \text{ amperes per leg.}$$

If no synchronous motor is used $C_{le} = 0$
Using equation (**16**), when $C_{l.} = 0$

$$K = \frac{13{,}200 - (43.7 \times 16.5) + 38.6 \times 13.3)}{13{,}200}$$

$$= \frac{14{,}436}{13{,}200}$$

K = 1.094, or line drop is 9.4 per cent of substation voltage at full load.

This means that the generator voltage V_G would be varied through 9.4 per cent from no-load to full-load on transmission line to keep constant voltage V_S at substation.

Equation (**17**) shows that adding reactance decreases the motor current, and consequently motor rating, as a general rule. Unless the line and transformer reactance amounts to 15 per cent, reactive coils should be installed so as to bring the total reactance to between 15 per cent and 20 per cent, and for the purpose of this example it will be assumed that reactive coils of 21.7 ohms reactance are used in addition to line reactance.

To determine size of synchronous motor from equation (**17**)

$$-C_m = \frac{(43.7)\ (16.5) + (38.6)\ (35)}{2\ (35)}$$

$$= 29.6 \text{ amperes per leg.}$$

Therefore the motor rating will be

$$29.6 \times 1.73 \times 13{,}200 = 675 \text{ kv-a.}$$

And to determine a constant ratio of generator voltage V_G to substation voltage V_S from equation (**18**)

$$K = \frac{1 + (43.7)\,(16.5) + (38.6)\,(35)}{2\,(13{,}200)}$$

$$= 1.0785$$

Thus, since full-load energy current is 43.7 amperes per leg, the synchronous motor must have a capacity equal to

$$\frac{29.6}{43.7} = 67 \text{ per cent}$$

of the energy being transmitted at full load and the generator voltage should be 7.85 per cent above substation voltage constantly.

The fact that both the generator voltage and the substation voltage will be constant, makes it feasible for an automatic voltage regulator to be operated in the field current of both the generator and synchronous motor, with the ratio

$$K = 1.0785$$

That is, the generator voltage should be 7. 85 per cent above substation voltage constantly, and the lagging current to establish the artificial drop under light load, and also the leading current to help to overcome the full load drop, are regulated automatically.

In order to make up charts for operating purposes, we wish to find the synchronous motor current for any proportion of full load on the transmission line. We can take equation (**15**), and since the leading current is to be supplied by a motor current we can substitute ($-\,C_m$) for (C_{le}), but since C has been used to denote full load values, we will take I for fractional load values. Rewriting equation (**15**) with these substitutions, we have

$$-\,I_m = \frac{V_S\,(1 - K) + I_{en}\,R + I_{la}\,X}{X}$$

This involves a value of K which is given in equation (**18**) in terms of full-load energies and full-load lagging currents.

$$K = \frac{1 + C_{en}\,R + C_{la}\,X}{2\,V_s} \qquad \textbf{(18)}$$

Substituting this value of K in equation (**15**) we get

$$-I_m = \frac{V_s\left(1 - 1 - \frac{C_{en}\,R + C_{la}\,X}{2\,V_s}\right) + I_{en}\,R + I_{la}\,X}{X}$$

$$-I_m = \frac{\frac{-C_{en}\,R + C_{la}\,X}{2} + I_{en}\,R + I_{la}\,X}{X}$$

$$-I_m = \frac{I_{en}\,R + I_{la}\,X}{X} - \frac{C_{en}\,R + C_{la}\,X}{2\,X} \qquad \textbf{(19)}$$

Substituting in equation (**19**) for half-load condition, we get

$$I_{en} = \frac{1}{2}\,C_{en}$$

$$I_{la} = \frac{1}{2}\,C_{la}$$

$$I_m = \frac{\frac{C_{en}}{2}\,R + \frac{C_{la}}{2}\,X}{X} - \frac{C_{en}\,R + C_{la}\,X}{2\,X}$$

$$I_m = \frac{C_{en}\,R + C_{la}\,X}{2\,X} - \frac{C_{en}\,R + C_{la}\,X}{2\,X}$$

$$I_m = 0$$

This means that the synchronous motor runs without wattless current at half load, at less than half load I_m is negative, that is, lagging current, and at more than half load I_m is positive, that is, leading, since leading current to the line is lagging current from the motor.

Line, Loss, Full Load. To find the influence that the application of the synchronous motor has on the line loss, we have the line current as previously stated.

$$C = C_{cn} + j\,C_{la} - j\,C_{le}$$

Rectifying,

$$C = \sqrt{C_{en}^2 + (C_{la} - C_{le})^2}$$

The line loss with synchronous motor is therefore equal to

$$[I_{en}^2 + (I_{la} - I_{le})^2]\,R \tag{20}$$

and without synchronous motor

$$[I_{en}^2 + I_{la}^2]\,R$$

The per cent line loss with motor, of the line loss without motor, is

$$100\,\frac{[I_{en}^2 + (I_{la} - I_{le})^2]\,R}{[I_{en}^2 + I_{la}^2]\,R}$$

$$100\left(1 - \frac{2\,I_{la}\,I_{le} - I_{le}^2}{I_{en}^2 + I_{la}^2}\right) \tag{21}$$

Numerical Example for Three-Quarter Load.

$$\begin{aligned} I_{le} = {} & \frac{(32.8 \times 16.5) + (28.9 \times 35)}{35} \\ & - \frac{(43.7 \times 16.5) + (38.6 \times 35)}{2 \times 35} \end{aligned} \tag{18}$$

$$I_{le} = 14.8$$

$$100\left(1 - \frac{2\,(28.9)\;(14.8) - (14.8)^2}{(32.8)^2 + (28.9)^2}\right) = 66.7 \text{ per cent} \tag{21}$$

the per cent line loss with motor, of the line loss without motor, at $\frac{3}{4}$ load.

Full Load.

$$100\left(1 - \frac{2\,(38.6)\;(29.6) - (29.6)^2}{(43.7)^2 + (38.6)^2}\right) = 58.6 \text{ per cent} \tag{21}$$

the per cent line loss with motor, of the line loss without motor, at full load.

The kw. line loss will be

$$[I_{en}^2 + (I_{la} - I_{le})^2]\, R \sqrt{3} \qquad \textbf{(22)}$$

Applying this to the numerical example:

a. At full load, with motor,

$$\begin{aligned} \text{line loss} &= [(43.7)^2 + (38.6 - 29.6)^2] \times 16.5 \times 1.73^2 \\ &= 56.9 \text{ kw.} \quad \text{(See Fig. 5)} \end{aligned}$$

b. At full load, without motor,

$$\begin{aligned} \text{line loss} &= [(43.7)^2 + (38.6)^2] \times 16.5 \times 1.73^2 \\ &= 97.1 \text{ kw.} \quad \text{(See Fig. 5)} \end{aligned}$$

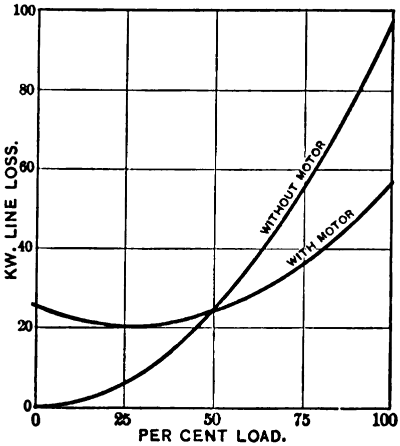

FIG. 5

c. At half load, $I_{le} = 0$, the line loss with motor is the same as the line loss without motor.

$$\begin{aligned} \text{line loss} &= [(21.8)^2 + (19.3)^2] \times 16.5 \times 1.73^2 \\ &= 24.3 \text{ kw.} \quad \text{(See Fig. 5)} \end{aligned}$$

The power factor will be

$$\text{Power factor} = \frac{\text{kw.}}{\text{kv-a.}} \qquad \textbf{(23)}$$

$$= \frac{I_{en} \times V_S \times \sqrt{3}}{\sqrt{I_{en} + (I_{la} - I_{le})^2 \times V_S \times \sqrt{3}}}$$

Applying this to the numerical example—

a. At full load, with the motor,

$$\text{power factor} = \frac{43.7 \times 13{,}200 \times \sqrt{3}}{\sqrt{(43.7)^2 + (38.6 - 29.6)^2} \times 13{,}200 \times \sqrt{3}}$$

$$= \frac{1000 \text{ kw.}}{1007 \text{ kv-a.}}$$

$$= 99.3$$

b. Under the assumed conditions of the numerical example, at full load, without the motor, we will have an inherent power factor of 75.

Assuming that the generating station is equipped with prime movers large enough to drive the generators at unity power factor and full load rating, it is apparent that raising the inherent power factor of 75 to a power factor of 99.3 with a synchronous motor under full load conditions, makes available considerable additional generator capacity to generate energy which can be sold. Therefore, there is an economic feature in connection with the operation of the synchronous motor. We will assume that the losses in the transmission line are not changed because the kv-a. load is to be kept constant, and the maximum economical condition will then be reached when operating at such a power factor that the income due to selling the additional energy, made available by improving the power factor, exactly balances the fixed charges, plus desired profit on the investment in the synchronous motor and necessary accessories (Kelvin's law.)

In solving the problem for the economical operating power factor, the following assumptions are made:

$KV\text{-}A_G$ is a constant value for generator output.

$KV\text{-}A_{la}$ is a constant value due to inherent characteristics.

$$\Delta KV\text{-}A_{le} = KV\text{-}A_{le_2} - KV\text{-}A_{le_1}$$

where $\Delta KV\text{-}A_{le}$ represents a small increase in leading wattless kv-a. which causes a small increase in power factor where $KV\text{-}A_{le2}$ represents the value of leading wattless kv-a. after the increase and $KV\text{-}A_{le1}$ represents the value of leading wattless kv-a. before the increase.

$$\Delta KW = KW_2 - KW_1$$

Where ΔKW represents a small increase in power made available by the small increase $\Delta\, KV\text{-}A_{le}$ and the resultant small increase in power factor.

The kv-a. output of the generator, which is assumed to be constant, can be expressed as follows:

$$\overline{KV\text{-}A_G}^2 = \overline{KW}^2 + (KV\text{-}A_{la} - KV\text{-}A_{le})^2 \qquad \textbf{(24)}$$

In order to determine the $KV\text{-}A_{le}$ to be supplied by the synchronous motor and necessary to increase the power factor of the generator kv-a. output, there is obtained from equation **(23)**.

$$KW = KVA_G \times P.F.$$

Substituting this value of $KW.$ in equation **(24)** we get

$$\overline{KV\text{-}A_G}^2 = (\overline{KV\text{-}A_G}^2 \times \overline{P.F.})^2 + KV\text{-}A_{la} - KV\text{-}A_{le})^2$$

Transposing,

$$(KV\text{-}A_{la} - KV\text{-}A_{le})^2 = \overline{KV\text{-}A_G}^2 - (\overline{KV\text{-}A_G}^2 \times \overline{P.F})^2$$

Extracting square root and factoring,

$$KV\text{-}A_{le} = KV\text{-}A_{la} - KV\text{-}A_G \sqrt{1 - \overline{P.F}^2} \qquad \textbf{(25)}$$

In the assumption $\Delta\, KW = KW_2 - KW_1$
substitute the value of kw. from equation **(23)**.

$$\Delta\, KW = (KV\text{-}A_G \times P.F_2) - (KV\text{-}A_G \times P.F_1)$$

Factoring,

$$\Delta\, KW = KV\text{-}A_G\,(P.F_2 - P.F_1) \qquad \textbf{(26)}$$

Equation **(26)** expresses the gain in kw. made available for sale by a certain increase in power factor. $(P.F_2 - P.F_1)$.

In the assumption $\Delta\, KV\text{-}A_{le} = KV\text{-}A_{le_2} - KV\text{-}A_{le_1}$
substitute the value of $KV\text{-}A_{le}$ from equation **(25)**

$$\begin{aligned} \Delta\, KV\text{-}A_{le} &= (KV\text{-}A_{la} - KV\text{-}A_G \sqrt{1 - \overline{P.F_2}^2}) \\ &\qquad - (KV\text{-}A_{la} - KV\text{-}A_G \sqrt{1 - \overline{P.F_1}^2}) \\ &= -\,KV\text{-}A_G \sqrt{1 - \overline{P.F_2}^2} + KV\text{-}A_G \sqrt{1 - \overline{P.F_1}^2} \\ &= KV\text{-}A_G\,(\sqrt{1 - P.F._1^2} - \sqrt{1 - P.F._2^2}) \qquad \textbf{(27)} \end{aligned}$$

Let S = selling price per kw. per year at substation busbars.

Let F = cost per year of each installed kv-a. of synchronous motor, rating, including interest, depreciation, and the desired earning upon the investment.

The sale of the small increase ΔKW will bring an income $\Delta KW \times S$ which will yield a profit if

$$\Delta KW \times S \overset{=}{>} \Delta KV\text{-}A_{le} \times F \quad \frac{\Delta KW}{\Delta KV\text{-}A_{le}} \overset{=}{>} \frac{F}{S} \tag{28}$$

In case there is any increase in manufacturing costs due to increase in available kw., such as additional cost of coal or any allowance for additional water used, said cost must be deducted from selling price per kw. (S)

Equation (**28**) will not indicate the economical power factor for the reason that part of a certain load ΔKW may be furnished at a loss and still the entire load may represent a profit. In order to determine the greatest economical power factor, there are obtained the first differential equations of equations (**23** and (**25**).

$$KW = KV\text{-}A_G \times P.F. \tag{23}$$

$$d\,KW = KV\text{-}A_G \times d\,P.F.$$

$$KV\text{-}A_{le} = KV\text{-}A_{la} - KV\text{-}A_G \sqrt{1 - \overline{P.F.}^2} \tag{25}$$

$$d\,KV\text{-}A_{le} = 0 - \frac{KV\text{-}A_G}{2\sqrt{1 - \overline{P.F.}^2}} \times -2\,P.F. \times d\,P.F.$$

$$d\,KV\text{-}A_{le} = \frac{KV\text{-}A_G \times P.F. \times d\,P.F.}{\sqrt{1 - \overline{P.F.}^2}}$$

Combining the two first differential equations by dividing $d\,KW$ by $d\,KV\text{-}A_{le}$ there is obtained

$$\frac{dKW}{d\,KV\text{-}A_{le}} = \frac{KV\text{-}A_G \times dP.F.}{KV\text{-}A_G \times \dfrac{P.F. \times d\,P.F.}{\sqrt{1 - \overline{P.F.}^2}}}$$

$$\frac{d\,KW}{d\,KV\text{-}A_{le}} = \frac{\sqrt{1 - \overline{P.F.}^2}}{P.F.} \tag{29}$$

This equation represents the rate of increase of power developed with respect to the increase in leading wattless kv-a. dKW and $d\,KV\text{-}A_{le}$ are infinitesimal values of ΔKW and $\Delta KV\text{-}A_{le}$.

From equation (**28**), an increase in kw. will show a profit if

$$\frac{\Delta KW}{\Delta KV\text{-}A_{le}} \overset{=}{>} \frac{F}{S} \tag{28}$$

The maximum value of power factor to yield desired earning is therefore determined by

$$\frac{d\,KW}{d\,KV\text{-}A_{le}} = \frac{F}{S}$$

Substituting this value of $\frac{d\,KW}{d\,KV\text{-}A_{le}}$ in equation (**29**) we get

$$\frac{F}{S} = \frac{\sqrt{1 - \overline{P.F.}^2}}{P.F.} \qquad \textbf{(30)}$$

This equation expresses the economical value above which it would not pay to increase the power factor by adding idle synchronous motor. Any increase in income derived from any increase in power factor beyond this point is less than the increase in fixed charges plus desired earnings on the additional investment for synchronous motor.

Applying the above analysis to our numerical example, we will first have to determine numerical values for F and S—

Cost per installed kv-a. of synchronous motor rating = \$20 (extreme)

Taking interest at	....	6 per cent
depreciation	"	6 " "
maintenance	"	3 " "
and profit	"	5 " "
		20 per cent (extreme)

F = 20 per cent × \$20 = \$4.

Price per kw. per year = 1ct. per kw. per hr. × 10 hr. per day × 300 da. per yr.

$$S = 0.01 \times 10 \times 300 = \$30$$

$$\frac{F}{S} = \frac{4}{30} = 0.133$$

$$\frac{\sqrt{1 - \overline{P.F.}^2}}{P.F.} = 0.133$$

$$\sqrt{1 - \overline{P.F.}^2} = 0.133\,P.F.$$

$$1 - \overline{P.F.}^2 = 0.0177\,P.F.^2$$

$$1.0177\,\overline{P.F.}^2 = 1$$

Power factor = 99.1

The current characteristics of a synchronous motor which make it adaptable for the purpose outlined in this paper, are shown in Fig. 3. The curves show how the armature current varies with a change in the field excitation, the mechanical load on the motor remaining constant in each case. The no-load curve is that taken with the motor running light. When there is no field current on the motor the machine runs like an induction motor, taking a large lagging current which supplies the magnetic flux required by the impressed e.m.f. When the field current is gradually increased in value from zero the armature current decreases while the power factor increases until the armature current is in time phase with the impressed e.m.f., at which point the m.m.f. of the field current is just sufficient to maintain the magnetic flux at the value demanded by the e.m.f. impressed upon the motor. The minimum input when the current is in time-phase with the e.m.f. represents the power loss in the motor; that is, core loss, friction and windage and a small amount of loss in the armature. If the field current is now further increased the motor will take from the line an increasing current which

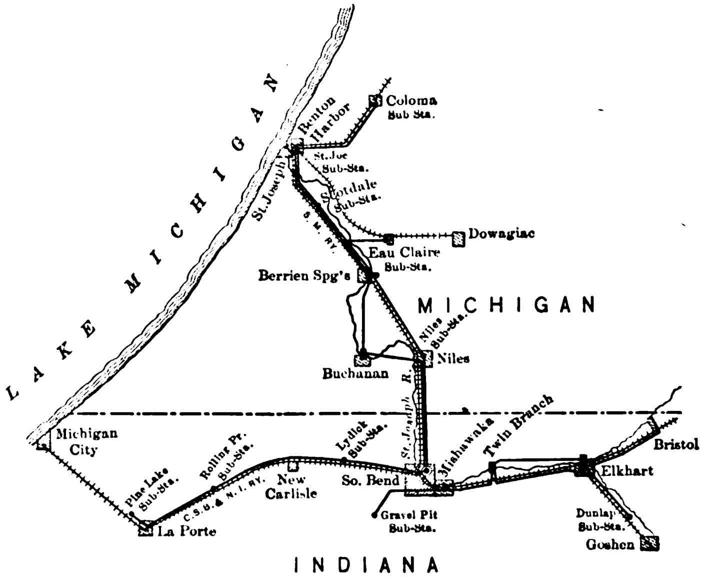

Fig. 6—Transmission System of Indiana and Michigan Electric Co., 1912.

leads the e.m.f., as is done in the case of synchronous motors running light as a " rotary condenser." The mechanical load on the motor can be increased to obtain any number of similar curves, two of which are shown, for three-quarter and full load, respectively. (See Fig. 3).

The distributing system of the Indiana and Michigan Electric Company is operated with two transmission voltages, 25,000 and 13,200. The 25,000-volt lines run from South Bend north and west and the 13,200-volt lines from South Bend east and south (see Fig. 6). The 13,200-volt and 25,000-volt distributing systems are tied together at South Bend switching station through three auto transformers, star-connected, with the neutral connected to ground.

It is not the intention of the writer to discuss the advisability of changing the transmission voltages to a standard or to enter into a discussion of the engineering features, but it is his purpose to present a brief outline of the system as it is now in operation. Attention is called to the location of the various power houses and substations, and it will be noted that the transmission lines constitute a high-tension distributing system rather than a high-tension transmission system, and for this reason a certain amount of switching at the transmission voltages was found to be necessary to get a proper grouping of transformers, lines, etc., in order that certain sections can be shut down for purpose of repairs while still maintaining a twenty-four hour service at all points. In every case 60-cycle plants have been installed, the power in the system is used for commercial and street lighting through all the territory covered by the company's lines, and although the company now has a number of railway substations in operation, the 60-cycle synchronous converter has been used successfully in these stations The power load has grown very rapidly, especially with the growth of new industries, as the investment for motors is considerably less than the investment for suitable steam plant, and in the larger installations there is a considerable saving in cost of power, neglecting the initial investment. The transmission voltages are such that it is possible to secure perfectly reliable oil switches for these voltages, and insulators are comparatively inexpensive as compared with the insulators in use on some of the higher voltage transmission lines, yet the lower voltage does not require proportionately heavy copper for the reason that the stations are but a comparatively short distance apart. All transmission lines feed a common-high-tension bus switching station in South Bend which is equipped with duplicate buses for better insuring continuity of service.

Wood pole line construction is used throughout, and for part of the distance there is side-arm construction on one side of the poles for transmission, the opposite side of the pole being used for bracket arms carrying street railway trolley wire and feeders. In cases of this kind where the poles are 100 ft. (30.48 m.) apart, the 25,000-volt lines are built on 30 in. (762-mm.) centers. All other construction on 25,000-volt lines is built on 36-in. (914-mm.) centers, and the 13,200-volt lines are built on 24-in. (61-cm.) centers. As the power load is an induction motor load almost exclusively, the generators and transformers were designed to operate continuously at about 85 per cent power factor, and a synchronous condenser is operating continuously at South Bend, St. Joseph and Elkhart, connected to the busbars, bringing the power factor from the inherent power factor of about 75 per cent to between 90 and 100 per cent.

The synchronous converters are compounded for giving as nearly as possible as straight-line voltage characteristic, taking into consideration the line characteristics, and although they are operating from transmission lines supplying lighting service, there are no noticeable fluctuations caused by them. The synchronous condensers operating at South Bend, St. Joseph and Elkhart have automatic voltage regulators in their field circuits, thus taking care of voltage fluctuations within range of the motor, and other variables affecting the regulation have been given considerable attention in laying out the system with the matter of voltage regulation in view. Considerable flywheel effect has been required when drawing specifications for the revolving element of the generators. In drawing specifications requiring short time of operation of water-wheel governors, the mechanical features were designed accordingly, with heavy gate shafts, gate operating mechanisms, etc., and although the additional weight of material increases the inertia effect, this is more than offset by the betterment in regulation due to the shortened time of operation of the governors. This, together with the fact that the whole system is connected together electrically, which secures the flywheel effect of the total load, makes it possible to secure very close voltage regulation on substation busbars.

All feeders leaving the power houses are protected with overload relays and are also provided with a full set of indicating instruments such as ammeters, power factor meters, indicating wattmeters, integrating wattmeters, etc., and in addition to this each feeder can be synchronized with the busbars by using the feeder oil switch. All oil switches are electrically operated with bull's-eye lamp indicators.

I wish at this point to call attention to the use which has been made of 60-cycle synchronous converters for railway work. As I have stated, they are compounded for giving as nearly as possible as straight-line voltage characteristic. In other words, the synchronous converters do not have the drooping voltage characteristic of a straight shunt-wound converter, neither do the machines have a rising voltage characteristic, such as would be caused by considerable over-compounding. The first synchronous converter substations were connected to the transmission lines between the main receiving station and the main generating station. There was a considerable amount of lighting service supplied from the receiving station busbars and the problem was to keep the line fluctuations, caused by the street railway load, from being detrimental to the receiving station voltage from a regulation standpoint. With automatic compounding, by use of series fields the power factor of the converter system varies and often varies widely with the load. A shunt-wound converter tends to keep the power factor the same at all loads, or the power factor on a shunt-wound converter can be adjusted by means of the field rheostat.

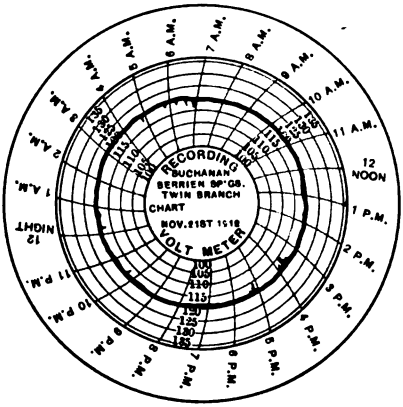

FIG. 7

The specifications for the first converters for use on railway work and which were to be operated from transmission lines supplying lighting service, called for converters which had a characteristic between that of a shunt-wound converter and that of an over-compounded converter. The shunt tendency of the d-c. characteristic, giving a flat d-c. voltage, had approximately the following effect on the converter capacity to prevent one converter drawing heavily on the transmission system. The direct-current voltage will be normal on light loads, but will tend to fall on full load. When the load is light on a substation, it will mean that most of the railway load on the system is being carried by other substations. The voltage will then be higher at the lightly loaded substation and lower at the more heavily loaded stations. The lightly loaded station will then tend to help out the heavily loaded one, resulting in a tendency to distribute the load proportionately between the substations at all times.

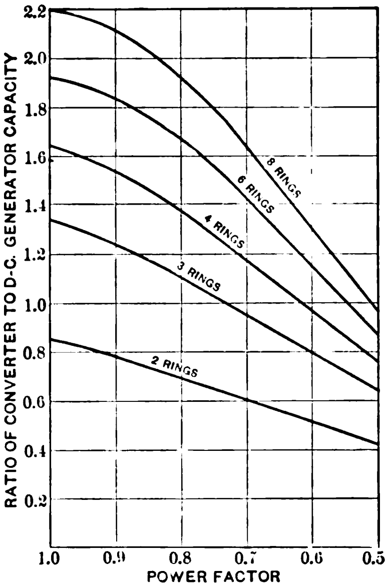

Fig. 8—Variation of Output Rating of Converters of Different Number of Phases (Collector Rings) with change in Power Factor.

This tendency to distribute the d-c. load evenly over the railway substations has the same effect on the input of the substation from the transmission line, that is, it keeps the input more nearly uniform than would be the case with overcompounded converters. This being the case, the converter can be excited so as to get about unity power factor at no-load and a leading power factor at all loads; then the increase in leading current due to the load coming on will automatically offset the line drop and help hold a flat voltage on the transmission line, and the shunt tendency of the converter will act to divide the load proportionately between all stations.

The conditions just described works out so nicely after installation that there was absolutely no detrimental effect from connecting the railway substations to the transmission lines supplying lighting service. In fact, recording voltmeter charts showed that the voltage conditions were somewhat improved. A recording voltmeter chart taken just before the holiday season, at South Bend, is reproduced in Fig. 7. and shows the voltage regulation which we are now getting on the system, and the chart is typical of the charts taken at any substation busbar connected to the transmission system of the Indiana and Michigan Electric Company. The capacity of the synchronous converters to handle the additional leading current to get the results described, was secured by lenghthening the bedplate casting and shaft and tapping the three-phase armature for six-phase operation. This increased the current-carrying capacity of the armatures for the same heating at the leading power factor at which the converters were operated (see Fig. 8). The d-c. output, of course, was not increased, as the commutator was the limiting feature and it was not the intention to gain any additional output capacity. It was the intention to increase the current-carrying capacity of the armature only in order to take care of the increase in leading current.

AIR AS AN INSULATOR WHEN IN THE PRESENCE OF INSULATING BODIES OF HIGHER SPECIFIC INDUCTIVE CAPACITY

BY

C. L. FORTESCUE and S. W. FARNSWORTH

Presented under the auspices of the

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ABSTRACT OF PAPER

The purpose of the paper is to show the conditions that determine the disruptive strength of an air path along the surface of a solid dielectric of higher specific inductive capacity, and what steps must be taken to insure the most efficient use of the two dielectrics in combination.

Part II of the paper discusses the effect on the electric field between two given terminals of the presence of a solid dielectric. An experimental means of determining the shape of the field is given. An explanation of the conditions that exist at the surface of the dielectric when in an electric field is given. The conclusion is drawn that if the surface of the dielectric be made tangential to the lines of force at every point, the strength of the path between the two given terminals will not be weakened.

Part III shows the results of applying this theory to practical purposes, such as insulating a terminal rod passing through a casing, and directing the external field on the standard form of condenser type terminals. In this portion of the paper, several curves are given, showing the distribution of potential over the surface of the dielectric.

Part IV gives the summary and conclusions, which are to the effect that breakdowns of an air path over a surface have been obtained, which average as high as 9.4 kv. per cm. effective value (23,900 volts per inch) over a distance of 17.0 cm. (6.7 inches). Conditions of design are such that these same averages may be maintained for any voltage, by increasing all dimensions of the structure proportionately. The strength of the air path in this form of design is independent of the specific capacity of the dielectric, and an important thing, therefore, is to shape the terminals properly in order to obtain a high average intensity over the given path.

A paper to be presented at the 281st meeting of the American Institute of Electrical Engineers, New York, March 14, 1913.

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AIR AS AN INSULATOR WHEN IN THE PRESENCE OF INSULATING BODIES OF HIGHER SPECIFIC INDUCTIVE CAPACITY

BY C. L. FORTESCUE AND S. W. FARNSWORTH

I. INTRODUCTION

The breakdown strength of air between conductors or terminals of different sizes and shapes when expressed in volts per cm. of separation, is a very variable value and of little significance. The great variation is not due to any difference in the strength of air for that is a physical constant, which, according to the results of many able investigators, has a value of between 30 and 38 kilovolts (maximum value) per cm. The variation is rather due to the influence of such factors as the shape and size of the terminals or conductors, and also to the position and potentials of these bodies relative to neighboring bodies. The case of comparative breakdown distances between spheres and needle points for a given voltage, furnishes an excellent illustration of this point. For example, with 25 cm. between spheres 25 cm. in diameter the air breaks down at 260,000 volts, whereas, it requires 67.3 cm. to withstand the same voltage between needle points. In the first case the volts per cm. are 10,400, whereas, in the second case the volts per cm. are 3870 (9800 volts per inch). Looking at air as a means of insulating a potential of 260,000 volts, it is evident that it serves much more efficiently in the case of the spheres than in the case of the needle points. When serving at its maximum efficiency, it will stand from 30 to 38 kilovolts (maximum) per cm. and for the purposes of this paper, the lower value will be assumed.

In most practical applications of air as an insulator, the problem is complicated by the presence of other dielectric media having a higher specific inductive capacity than that of air. There is, in general, a false conception of the parts played by the two media, namely, the solid dielectric and air, in performing their functions in the insulator. With increased voltage, the part the air plays becomes more and more important and at present day voltages should no longer be disregarded. While the breakdown voltage of air alone, as expressed in volts per cm., is a very variable quantity, the breakdown voltage of air over the surface of a solid dielectric when expressed in the same terms (a value commonly called "creepage" voltage) is still more variable and of even less significance.

As there are ways, as illustrated above, of using air alone more efficiently than is ordinarily done, so are there ways of using the combination of air and a solid dielectric more efficiently. It is the purpose of this paper to show the conditions that determine the disruptive strength of an air path along the surface of a solid dielectric of higher specific inductive capacity. and what steps must be taken to insure the most efficient use of the two dielectrics in combination.

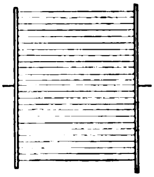


FIG. 1.

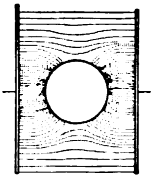


FIG. 2.

II. THE ELECTRIC FIELD IN THE PRESENCE OF SOLID DIELECTRICS

The effect of introducing an insulating body into the static field between two conductors is to increase the stress in the air path at the surface of the conductor and at the surface of the insulating body, unless certain laws governing the proper shaping of the body, which will be stated later, are observed. This statement may be easily verified experimentally, by placing a glass sphere in the electrostatic field between two parallel plates maintained at different potentials. If the static field is intense enough, the introduction of the sphere will cause corona to form at the surface of the sphere and at the contiguous parts of the two plates; the air between the plates will consequently break down at a much lower voltage than if the glass sphere were absent.

Fig. 1 shows the condition of the static field before the introduction of the glass ball. Fig. 2 gives an idea of the condition of the field after the glass ball has been introduced. It will be seen that the lines of force concentrate in the glass ball and are more dense at its surface and at the portion of the surface of the two plates nearest the ball than anywhere else.

A close analogy to the action which takes place when the glass sphere is introduced into the electric field is obtained by placing a steel ball in the magnetic field between two large poles of opposite polarity. In this case the field may be mapped out with iron filings.

Fig. 3 shows a method of plotting the equipotential surfaces of the current flow between two conductors which are similar to the equipotential surfaces in the electric field between terminals of similar shape. To obtain the equipotential surfaces or current flow, current is passed between the two terminal plates suspended in a conducting liquid. Between the plates is suspended a metal ball. An insulated exploring lead is taken from any given point on the calibrated resistance placed across the supply voltage and carried into the liquid, where it terminates in an uninsulated point. The needle is moved about, always keeping the galvanometer zero, thus indicating the location of points of the same potential as the chosen point on the resistance. The movement of the exploring needle is recorded by means of a pantograph.

Fig. 4 shows one of many charts taken according to the method shown in Fig. 3. The bath used in this case was salt water, and the two terminal electrodes a cylinderical rod and a torus ring in the relative positions indicated. The wavy lines show the observed equipotential surfaces. The small circles indicate points of definite observed potential. The smooth lines show theoretical equipotential surfaces of indicated potential for the given terminals. Having obtained the equipotential surfaces, the lines of flow may be drawn in at right angles to them. If in Fig. 3 the sphere should be steel and the bath mercury since the conductivity of iron is about ten times that of mercury, the field obtained would resemble very closely the field for the glass sphere in air, the specific inductive capacity of glass being about eight.

The conditions that exist at the surface of the dielectric of high specific inductive capacity in a field of force in air are brought about as follows: A given difference of potential will cause a very much greater electric flux in the solid dielectric than in air. At the surface of separation of the air and the solid the tangential component of the intensity must be the same in the air as in the solid. Since it requires *K* times the force to produce the same dielectric flux in the air as in the solid, where *K*

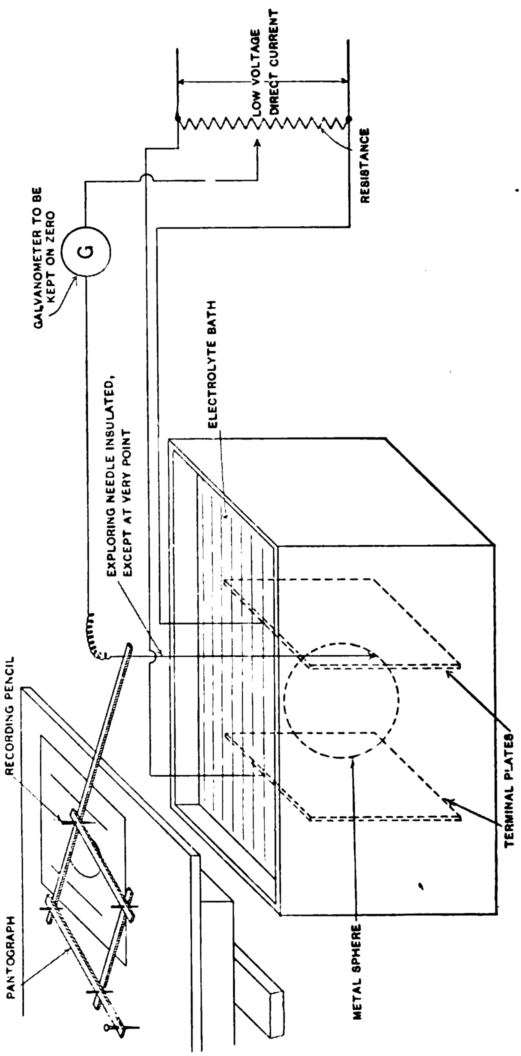


FIG. 3.

is the value of the specific inductive capacity of the solid dielectric the component of intensity in the air normal to the surface will be K times that in the solid dielectric. The intensity at each point of the surface of separation is increased from what it was

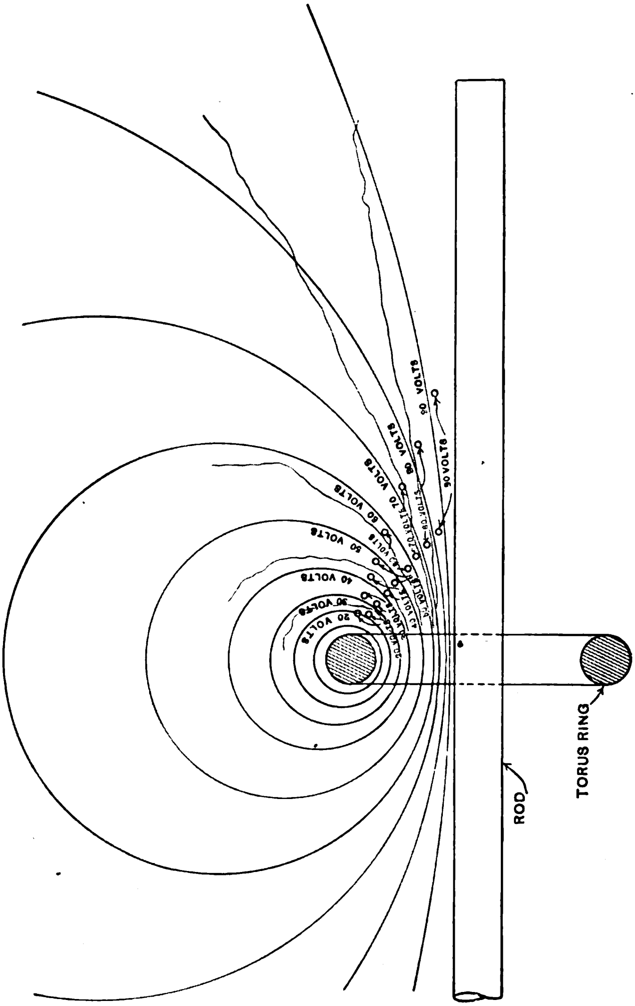


Fig. 4.

before the introduction of the dielectric and is more nearly normal to the surface. If the solid body extends from one conductor to the other, we may have a condition in which the tangential component of the intensity will be nearly uniform, but the maximum intensity being in a direction more nearly normal to the surface than before the introduction of the solid, its value is greater at every point. The air path along the surface is, therefore, weaker than before the introduction of the dielectric. If, however, we form the dielectric so that its surface is tangential to the lines of force at every point, then there will be no normal component of intensity; the tangential intensity at each point of the surface will be the same as before the introduction of the solid and the strength of the air path will remain unchanged.

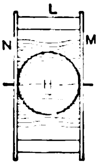


FIG. 5.

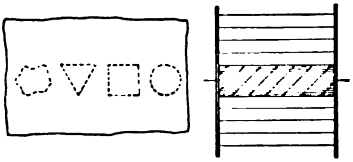


FIG. 6.

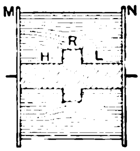


FIG. 7.

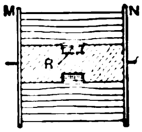


FIG. 8.

To illustrate this by simple examples, let us consider the sphere to extend from one plate to the other, then the field will have the form shown in Fig. 5. Comparing this with Fig. 1, it is seen that the stress along the surface of the sphere adjacent to the plates has been very much increased. Suppose that we substitute for the glass sphere a glass cylinder, or any solid shape with a surface

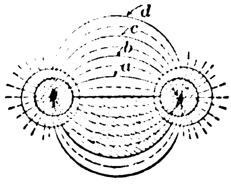


FIG. 9.

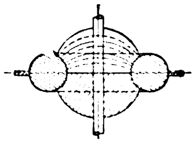


FIG. 10.

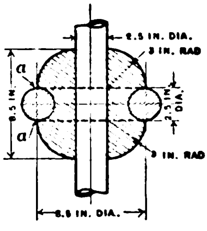
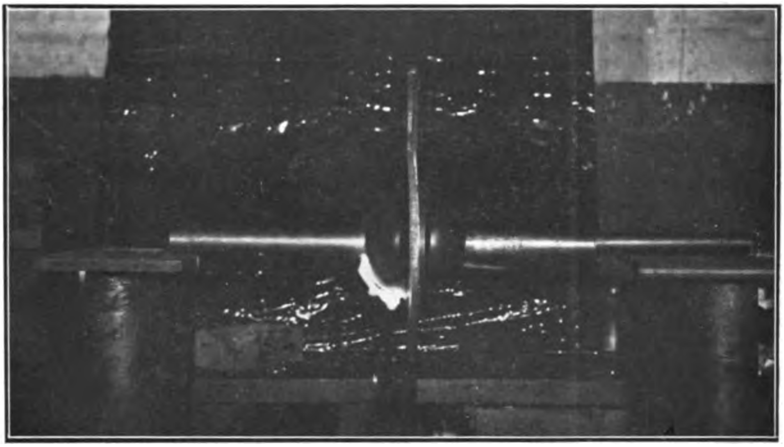


FIG. 11.

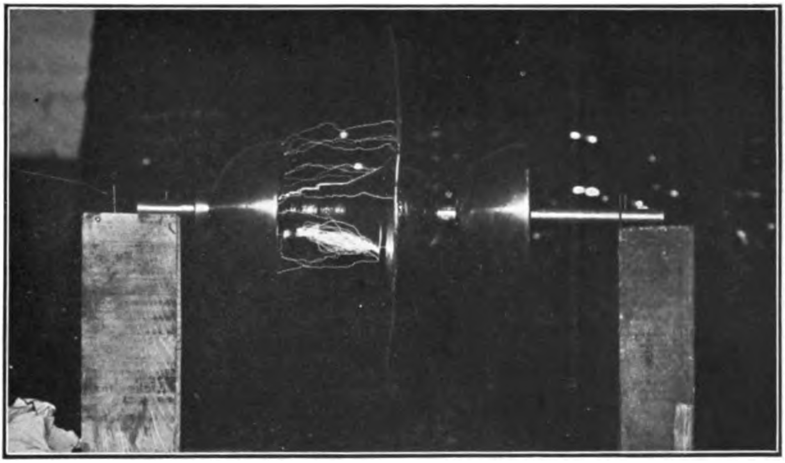
generated by a line perpendicular to the planes as in Fig. 6, then there will be no increase of stress either at the surface of the solid or at the surface of the plates. In the first case, the introduction of the solid has decreased the breakdown strength by a large amount, but in the second case the strength is unimpaired by the introduction of the solid. Fig. 7 shows two planes, *M* and *N*, having a piece of insulating material extending continuously between them with a projection in the middle such as



[FORTESCUE AND FARNSWORTH]

FIG. 12

(Circular light spots due to shiny background and have nothing to do with the discharge.)



[FORTESCUE AND FARNSWORTH]

FIG. 21

(Circular light spots due to shiny background and have nothing to do with the discharge.)

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ASTOR, LENOX AND
TILDEN FOUNDATIONS

is commonly employed to give increased "creepage" distance. In the light of the previous explanation, it is seen that the air in the path *HL* will be stressed to a higher value than if the projection *R* were not present. That is to say, the very thing which is ordinarily sought for, namely, an increased distance over the surface, is shown to be detrimental in this case rather than beneficial. The higher the specific inductive capacity of the material, the more detrimental is the projection.

Should a groove be placed in the insulating material as in Fig. 8, another very poor condition is obtained, as the air at *R* will be stressed beyond its limit at a comparatively small difference of potential between *M* and *N*.

The cross-hatched portion of the lower half of Fig. 9 shows how the insulation would have to be shaped to insulate two parallel wires with a maximum efficiency. The surface could be made to conform to any one of several flow lines, *a*, *b*, *c*, etc.

III. PRACTICAL APPLICATION OF THEORY WITH RESULTS OF TESTS

Fig. 10 shows a means of insulating a terminal rod passing through a casing. Experimental pieces of this design were made up to dimensions shown in Fig. 11. The material used was a mixture of shellac, whiting and various gums. The bushing was cast in an accurately machined mould. A maximum breakdown of 145 kv., effective value, was obtained, and when good care was taken to have a clean surface, the breakdowns were seldom less than 135 kv.

Fig. 12 shows a breakdown at 137 kv. on one of these bushings and it will be noticed that there are no evidences of corona at any point of the surface.

Fig. 13 shows the calculated intensity curve for the surface path. Assuming a maximum allowable intensity of 19.7 kv. per cm. (50 kv. per in.), effective value, at the points of highest intensity which are at the surfaces of the ring and rod, by integrating the area under the curve, we obtain the voltage necessary to break down the path, which on the above assumptions is 142 kv. It will be noted from the curve that the minimum intensity is 9.1 kv. per cm. (23.2 kv. per in.) or slightly less than half the maximum value. The distance over the surface is 11.9 cm. (4.7 in.) so the average volts per cm. for a breakdown voltage of 145,000 is 12.2 (31 kv. per in.).

The dimensions of ring and rod chosen were such as to give a maximum breakdown voltage over the surface for a mean diameter of torus ring of 21.6 cm. (8.5 in.). The surface of the solid was made to conform to the flow lines, leaving the torus ring on line *a*, Fig. 11. Any other set of flow lines might have been chosen. Had a set been chosen leaving outside of lines *a*, there would have been difficulty in casting the bushing due to the back draft on the mold. If a set of lines had been chosen leaving inside of lines *a*, there would have been a pocket to catch dirt.

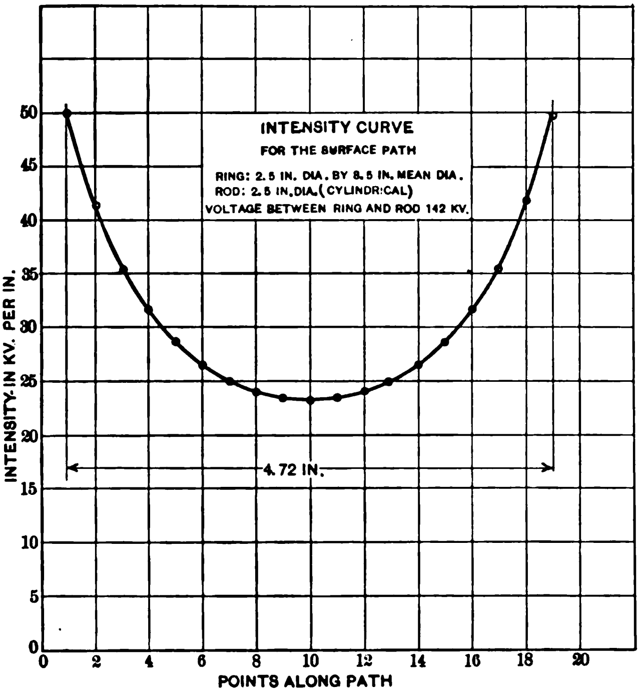

FIG. 13.

The law of similar fields applies to these cases, so if all the dimensions of Fig. 11 be doubled, the breakdown voltage should be doubled.

As a matter of interest, the approximate intensities existing through the insulating material along the line of minimum separation between ring and rod were calculated, and are given in Fig. 14, considering a voltage of 142,000 applied. The intensity is seen to be less at the ring than at the rod, and for the given voltage, the intensity at the rod is 46 kv. per cm. (117 kv. per in.)

effective value. Ordinary insulating material should be capable of standing this voltage without being unduly stressed. This is the more evident when we consider that air itself is capable of standing 21 to 27 kv. per cm. (54 to 68 kv. per in.)

The above analysis of the intensities in the solid dielectric suggests that to find the real strength of insulating materials, some form of terminals should be used which will permit calculation of the stress at the point of maximum intensity when breakdown occurs.

In order that the great gain which can be made by properly designing the surface of the solid dielectric may be more evident, attention is called to the breakdown over the surface of a former standard transformer bushing and an ordinary line insulator. Fig. 15 shows the transformer bushing which was formerly a standard for 66,000-volt work and which would flash over its 81½ cm. (32 in.) of surface at a voltage of about 145,000. In the bushing shown in Fig. 13, a distance of 11.9 cm. (4.7 in.) breaks down only when this same voltage is reached. Fig. 16 shows an ordinary line insulator having a surface distance of 63.5 cm. (25 in.) which breaks down at 119,000 volts.

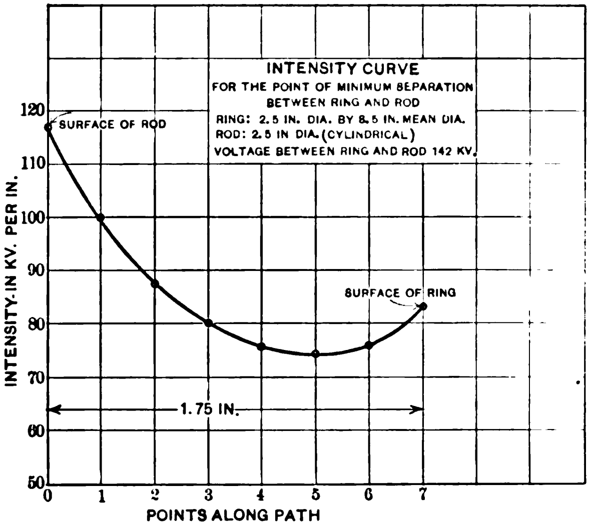

FIG. 14.

By changing the shape of the terminals it is possible to design a bushing which will have a higher average intensity over the surface before breakdown of the air will occur. Fig. 17 shows an arrangement similar to that of Fig. 11, which accomplishes this. Allowing the same mean diameter of torus ring, 21.5 cm.(8½ in.), as used in Fig. 11, and the same maximum intensity in the air, we see from Fig. 18 that the calculated breakdown voltage will be 181 kv. The minimum intensity is 13.2 kv. per cm. (33.5 kv. per in.) as against 9.15 kv. per cm. (23.2 kv. per in.) for the bushing shown in Fig. 11. Fig. 19 shows the calculated maximum intensities in the solid, which are 179 kv. per cm. effective value, (455 kv. per in.) at the surface of the rod. Judging from our tests, it seems reasonable to expect that what are ordinarily considered as good insulating materials, will be capable of standing this intensity. This piece has not been made up, however.

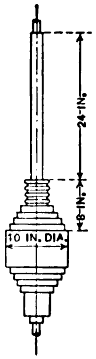

Fig. 15.

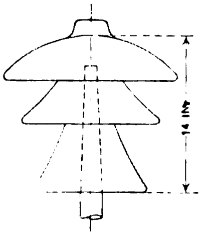

Fig. 16.

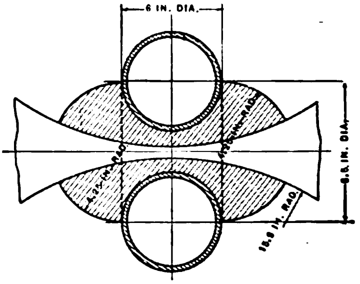

Fig. 17.

Fig. 20 shows a different design, using a confocal system of ellipsoids and hyperboloids of revolution, having foci which are 5.08 cm. (2.0 in.) apart. A piece was turned out of hard rubber to the given dimensions and the average breakdowns over the surface have been above 160,000 volts; thus giving an average of 9.4 kv. per cm. (23,900 volts per in.) for a surface distance of 17.0 cm. (6.7 in.). These values are striking when compared with the breakdown voltage of 145,000 volts for 81½ cm. of surface of the bushing shown in Fig. 15. In that case the average kilovolts per cm. are 1.78 (4.54 kv. per in.).

This piece was placed where it would collect dust and dirt such as it would be likely to in indoor service and was tested after three months. It showed no deterioration in breakdown strength, even with this heavy coating of dust.

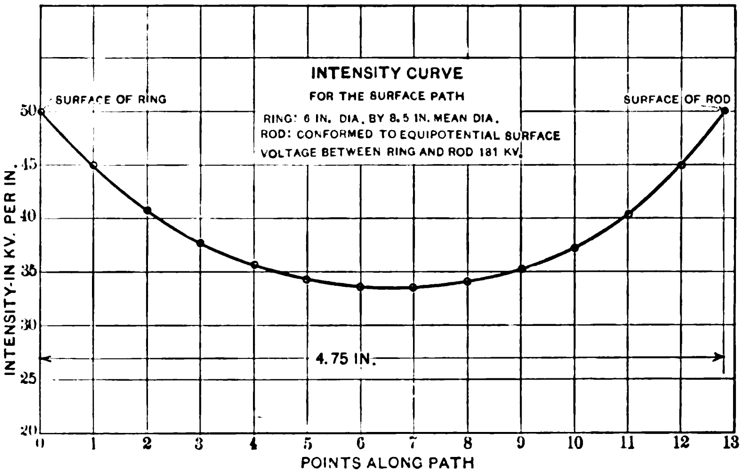
INTENSITY CURVE
FOR THE SURFACE PATH
RING: 6 IN. DIA. BY 8.5 IN. MEAN DIA.
ROD: CONFORMED TO EQUIPOTENTIAL SURFACE
VOLTAGE BETWEEN RING AND ROD 181 KV.
SURFACE OF RING
SURFACE OF ROD
4.75 IN.
INTENSITY-IN KV. PER IN.
50
45
40
35
30
25
20
0
1
2
3
4
5
6
7
8
9
10
11
12
13
POINTS ALONG PATH

FIG. 18.

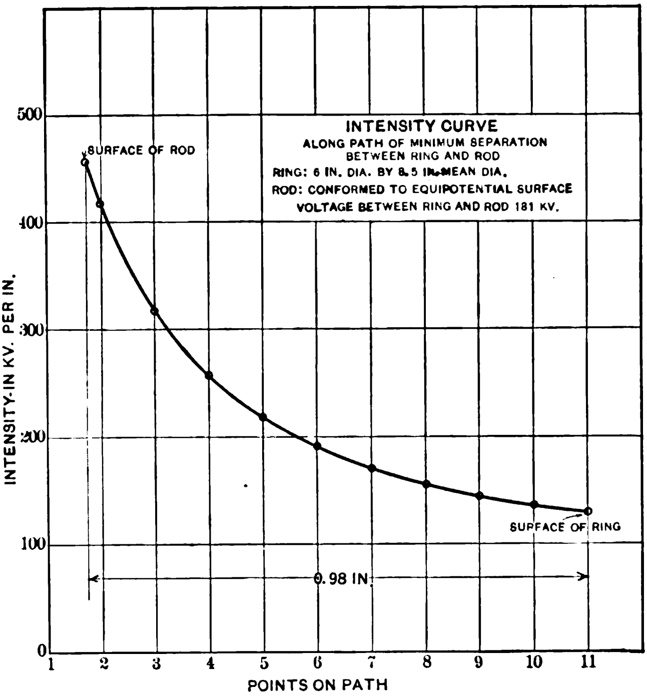
INTENSITY CURVE
ALONG PATH OF MINIMUM SEPARATION
BETWEEN RING AND ROD
RING: 6 IN. DIA. BY 8.5 IN. MEAN DIA.
ROD: CONFORMED TO EQUIPOTENTIAL SURFACE
VOLTAGE BETWEEN RING AND ROD 181 KV.
SURFACE OF ROD
SURFACE OF RING
0.98 IN.
INTENSITY-IN KV. PER IN.
500
400
300
200
100
0
1
2
3
4
5
6
7
8
9
10
11
POINTS ON PATH

FIG. 19.

Fig. 21 shows a rather crude, but none the less instructive and convincing experiment. The arrangement of parts and their dimensions are shown in Fig. 22. The illustration shows how the longer path, having insulation stepped off in the conventional way, broke down without distressing the shorter end in the least.

Fig. 23 shows a possible adaptation of this principle to an insulator which is shown as of the suspension type, but which might be slightly modified and made pin type.

The applications of the principle of shaping terminals and dielectric spoken of thus far, have embodied new designs of each. In the condenser type bushing we may have an ideal even distribution of potential on the surface. The full benefit of this distribution cannot be obtained, however, unless the external field is properly cared for. As an excellent illustration of this statement, the following test on a large terminal is given. This particular terminal had a maximum diameter of about 30.5 cm. (12 in.) and was about 203 cm. (80 in.) high. As originally designed, a metal disk was provided on the top end, which was 40.6 cm. (18 in.) in diameter with a 3.8 cm. (1.5-in.) pipe welded on its outer edge. Under test, corona was visible from the edges of the disk at 300,000 volts; at 400,000 volts there was a great deal of corona, and the small metal rings at the ends of the tinfoil coatings at the top steps were beginning to glow; at 430,000 volts is was deemed inadvisable to either hold the voltage or to raise it any higher for fear of a complete breakdown. A new disk was designed for the top of the terminal and the dimensions

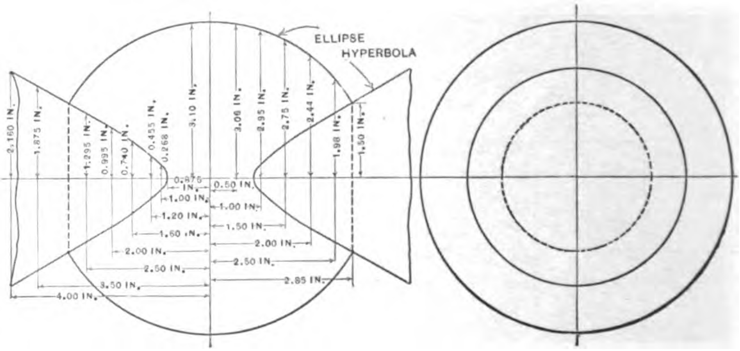

FIG. 20.

selected were 152.5 cm. (60 in.) diameter and 30.5 cm. (12 in.) thickness, with edges having a radius of 15.25 cm. (6 in.). The disk was made of wood and covered with tinfoil. The results obtained with this new disk were rather startling. At no voltage up to 575,000, the maximum voltage tried, was there any appreciable corona. There were occasional bunches of bluish fan-shaped haze emanating from some piece of dirt or rough spot on the disk toward the iron framework of the building which happened to be near the terminal. The body of the terminal itself showed not the slightest sign of a glow on any of the steps. Thus, by means of a very inexpensive change of design, the terminal was able to stand 575,000 volts as satisfactorily as it had stood 300,000 volts previously. This was accomplished simply by relieving stresses in the air at the top end of the terminal, and also redirecting the field adjacent to the surface of the terminal, so that the equipotential surfaces in the air were evenly distributed, corresponding to the even distribution secured by the condensers. Fig. 24 gives some idea of the distribution of the field under the two conditions.

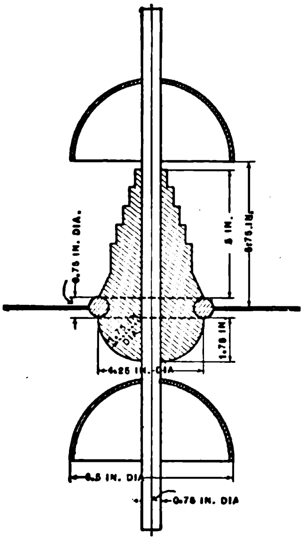

Fig. 22.

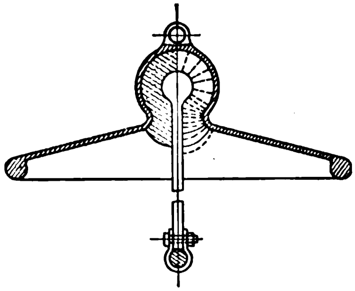

Fig. 23.

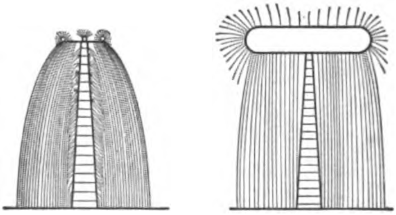

Fig. 24.

IV. Summary and Conclusions

We have given, in this paper, a new conception of the functions which air and a solid dielectric perform when used in combination for insulating purposes. Based on this conception, a large number of tests have been made under commercial conditions, which show that it is possible to use air more efficiently than has been customary in the past. Breakdowns of an air path over a surface have been obtained which average as high as 9.4 kv. per cm., effective value, (23,900 volts per in.) over a distance of 17.0 cm. (6.7 in.). The conditions of design are such that these same averages may be maintained at any voltage, by increasing all dimensions of the structure proportionately.

A maximum efficiency of air path over a surface is obtained when the surface of the dielectric is made to conform to the flow lines between the terminals. The strength of such a path is independent of the specific inductive capacity of the dielectric. The principal thing to be considered, therefore, is the proper shaping of the terminals in order that points of high intensity may be eliminated and a high average intensity obtained for the given path.

It seems to the authors that there exist great possibilities of improvement in present designs of terminal bushings and high tension insulators, when considered from the standpoint outlined in this paper. It was with a view to stimulating research along these lines that this paper was written.

Acknowledgment is made to Mr. K. C. Randall, for his participation in the early investigations on this subject.

Several of the authors' associates have closely followed the tests described above and have reviewed the results. Our thanks are due to Messrs. H. J. Ryan, C. F. Scott, L. W. Chubb, J. A. Sandford, Jr., H. B. Smith, B. G. Lamme, H. E. Clifford and C. E. Skinner for the interest they have taken in this investigation.

THE APPLICATION OF A THEOREM OF ELECTROSTATICS TO INSULATION PROBLEMS

BY

C. FORTESCUE

Presented under the auspices of the

Electrophysics Committee

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THE APPLICATION OF A THEOREM OF ELECTROSTATICS TO INSULATION PROBLEMS

BY C. FORTESCUE

ABSTRACT OF PAPER

The arrangement of conductors so that they shall assist in insulating one another has received but little consideration. The object of this paper is to emphasize a principle of electrostatic theory by which this may be done. A statement of this principle is: " If a region in any particular electric field be isolated or cut out by any number of closed surfaces then the electric field in this region will remain unchanged, whatever change may take place in the external field, if the potentials at all points on the enclosing surfaces are maintained at their original value." A discussion of the principle follows and illustrations of electrostatic fields produced by its means.

Limitations imposed on practical applications of the principle are discussed. Application to core-type transformers is considered. Arrangements suitable for various conditions of service are described and a description is given of a transformer which was built according to this principle, and tested. Application to shell-type transformers and to outlet terminals and insulators is shown. Condenser type terminal affords an example of the advantage obtained by conforming to this principle. Suggestions are made as to its application to line insulators.

This principle is capable of wide application and seems to afford a solution of some of the most perplexing problems confronting electrical engineers.

A paper to be presented at the 281st meeting of the American Institute of Electrical Engineers, New York, March 14, 1913.

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THE APPLICATION OF A THEOREM OF ELECTROSTATICS TO INSULATION PROBLEMS

BY C. FORTESCUE

I. INTRODUCTION

In the early days of the electrical industry, the problem of insulation was solved by taping the conductors to be insulated with some kind of textile material saturated with an insulating compound. Present day methods of insulation, while showing marked improvement over those in the past, still retain the influence of early tradition, and are largely based on rule of thumb. This condition of affairs may be ascribed to the very rapid development of high-tension transmission systems, and the consequent immediate demand for apparatus insulated for high voltages. The development has been so rapid that engineers have had no time for a proper study of the problem.

One aspect of the problem that has received but little consideration is the proper grouping of conductors, so that they shall assist in insulating one another. To illustrate this idea by an example that will be familiar to everyone, consider two spheres 25 cm. in diameter and 25 cm. apart, at potentials + 200,000 and − 200,000 and a small thin disk of conducting material connected to ground and placed near the spheres. The disk may be placed in a number of positions in which it is insulated from both of the spheres, but there is only one set of positions in which it will cause no disturbance of the electric field, namely, those lying in the zero potential surface or plane of symmetry midway between the two spheres. If one of the spheres be removed, the balance will be disturbed and the remaining sphere will discharge to the disk. Thus the presence of the sphere of potential + 200,000 has served to insulate the sphere of potential − 200,000 from the grounded disk. Very thin wires may be brought into the field of the two spheres and maintained at a difference of potential many times larger than their normal disruptive voltage.

In such cases as these the ordinary rules of procedure followed in insulation methods are seemingly violated. Thus sharp edges and fine wires are more effectively insulated than thick rounded edges and large wires. In practical work, conductors usually have edges where the intensity becomes high, and therefore, if by some method, these sharp edges can be insulated as effectively as large rounded edges, a valuable advantage will have been gained.

The object of this paper is to emphasize a principle of electrostatic theory by which the individual units of a system of conductors may be arranged to protect one another. The statement of the principle and several illustrations are given in Section II following.

II. STATEMENT OF PRINCIPLE OF ELECTROSTATIC THEORY WITH ILLUSTRATIONS

If a region in any particular electric field be isolated or cut out by any number of closed surfaces, then the electric field in this region will remain unchanged, whatever change may take place in the external electric field, if the potentials at all points on the enclosing surfaces are maintained at their original values.

It follows from the above that the intensity due to the surface distribution will, at each point of the region, be the same as that of the assumed electric field. The potential in such a region will be unaffected by any change in position or electrification of external bodies, since it is uniquely determined by the surface potential distribution which remains unchanged.

It is also obvious from this principle that two or more regions, completely separated from one another by any number of surfaces, may each have a different electric field, if at every point of the dividing surface or surfaces between any two of the regions, the fields in these regions have the same potential.

The truth of the principle just stated is almost self-evident, for it is known that when the potentials of a system of conductors are given, there is only one possible solution of the electric field consistent with the proper conditions. If, therefore, a solution be known that will give the same potential at each point of the bounding surfaces of a given region, as the assigned potentials, then this must be the only possible solution. It is not so easy to see that the field within the region is independent of any external influences. This may be deduced from the fact that, in order to produce a potential within the region, an external system must also produce a potential at each point of the surfaces, and, since the potentials at the surfaces are maintained constant, the effect of external bodies within the region must be zero. Changes in the external electric field have the effect, however, of altering the charges at each point of the surface. In other words, the effect of any change in the external system is to produce a change in the capacity of the system of charged bodies at the surfaces of the region, in such a way that there is a change in the surface charges, the potentials remaining constant, of such a nature as to completely annul the effect within the region of the change in the external system.

The analytic theorem upon which this principle is based may be found in Maxwell's " Electricity and Magnetism," 1904 edition page 136, Article 99.(b). A more general proof af the same theorem is given in Kelvin and Tait " Treatise on Natural Philosophy," 1903 edition, Vol. 1, Chapter 1, Appendix A (c). A full discussion of Green's problem, which has some bearing on the above principle, may be found in Volume 2 of the same work, Articles 499 to 508 inclusive. Reference may also be made to Jean's " Electricity and Magnetism," Articles 186, 187 and 188, and to Webster's "The Theory of Electricity and Magnetism," the last paragraph of Article 86.

A few simple illustrations of electric fields produced in accordance with this principle may serve to give a more vivid conception of its use.

Consider two parallel plane conductors, forming two portions of the surface of a solid dielectric. To produce within the body a uniform field corresponding to that between two infinite parallel plates having the same potentials as the two conductors, all that is necessary is to produce at each point of the surface of the dielectric a potential equal to that of the uniform field at that point. The whole surface of the dielectric might be considered as mapped out in equi-potential contour lines infinitely close together and each line may be imagined to become a conductor which will be supposed to be connected to an external source of the proper potential.

A dielectric sphere in a uniform field furnishes an interesting application of this principle. If the potential of the field be $V = R\,x$, and if the center of the sphere be at the origin and its radius be a, any distortion of the field due to the difference in specific inductive capacity of the sphere from air may be prevented by maintaining, at the surface of the sphere, a potential distribution,

$$V_s = R\,a \cos\theta$$

Under this condition, the potential both inside and outside the sphere will be,

$$V = R\,x$$

Without the surface distribution, the potential inside the sphere would be,

$$V_1 = \frac{3}{K+2}\,R\,x$$

and that outside the sphere would be,

$$V_0 = R\,x\left\{1 - \frac{K-1}{K+2}\left(\frac{a}{r}\right)^3\right\}$$

The maximum value of the intensity at the surface of the sphere in the air would be,

$$R_0 = \frac{3\,K}{K+2}\,R$$

Thus if $K = 4$, $R_0 = 2\,R$. The intensity therefore has been doubled at the maximum point by the introduction of the sphere.

It is interesting to find the surface distribution of electricity produced on the sphere by the potential distribution, V_s over the surface. Let V_2 be the internal pôtential due to this surface distribution of electricity. Then

$$V_2 = R\,x - V_1$$

$$= \frac{K-1}{K+2}\,R\,x$$

The surface density required to produce this internal potential is

$$S = \frac{3\,(K-1)}{4\,\pi\,(K+2)}\,R\cos\theta$$

The external potential due to this surface density will be

$$V_3 = \left(\frac{a}{r}\right)^2 \frac{K-1}{K+2}\,R\,a\cos\theta$$

or since

$$r \cos \theta = x$$

$$V^3 = \left(\frac{a}{r}\right)^3 \frac{K-1}{K+2} R x$$

and this when added to V_0, the external potential obtained without the potential distribution, gives the potential outside the sphere when the surface potential distribution is determined according to the principle. That is,

$$V_0 + V_3 = V = R x$$

A section of the equipotential surfaces of the electric field in the neighborhood of a dielectric sphere ($K = 4$) in a uniform field, with and without the proper potential distribution, is shown in Figs. 1 and 2.

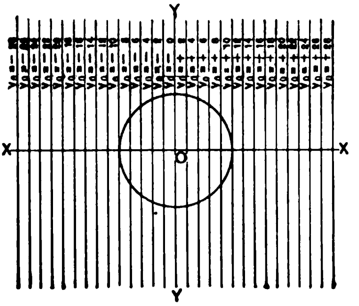


Fig. 1—Section by Plane Passing through Axis of x of Equipotential Surfaces of Dielectric Sphere in a Uniform Electrostatic Field.

The sphere has the proper potential distribution over its surface to insure no distortion of the field.

Cylindrical conducting bodies and insulating structures are of common occurrence in practical problems. Suppose it be required to insulate a short external cylinder from a long internal concentric cylinder. A line may be drawn from the ends of the external cylinder to the nearest point on the ends of the inner cylinder, see Fig. 3. The surfaces of revolution formed by these two lines and the two cylinders may be taken as bounding surfaces of the enclosed region, which will be assumed to have within it a potential

$$V_1 = B \log_e r + A$$

where r is the distance of the point, whose potential is V_1 from the axis of the cylinders and B and A are constants determined from the potentials of the two cylinders. The equipotential surfaces of the field will intersect the surfaces of revolution formed by the two lines in circles, the planes of which will be perpendicular to the axis of the cylinder. If each circle were a conductor connected to an outside source having the same potential as that of the equipotential surface on which the circle lies, the distribution over the surface so produced would cause the potential within the enclosed region to be equal to

$$V_1' = B \log_e r + A$$

If, instead of the external cylinder, a disk be substituted of infinite radius with a hole in it of the same diameter as the cylinder, and with its plane at right angles to the axis of the cylinders, and if the internal cylinder be provided with a similar disk at each end; taking z as measured from the point of intersection of the axis of the cylinder and the plane of the middle disk, a field may be assumed between the middle and upper disks, having its equipotential surfaces parallel to the disk, and the potential of the field will be

$$V_0 = C + D z$$

C and D being determined by the potentials of the middle and outer disks.

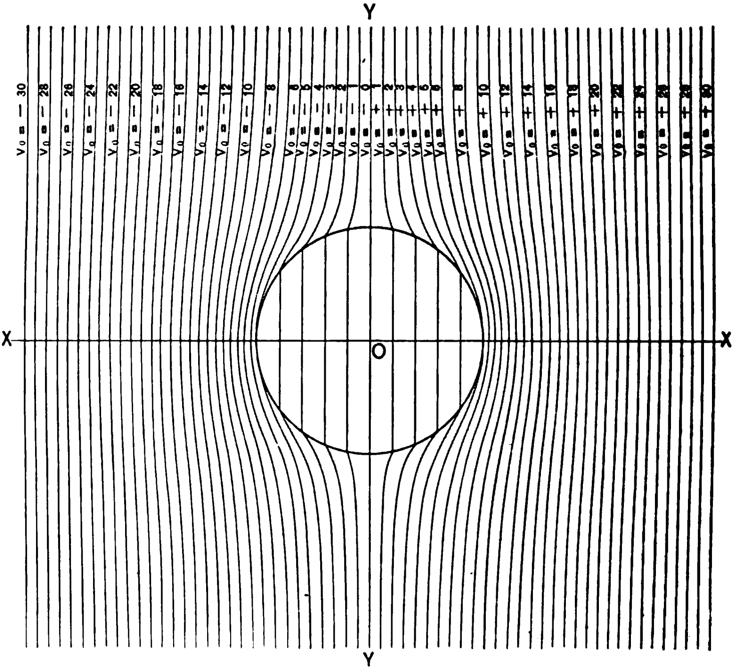


FIG. 2—DIELECTRIC SPHERE (K = 4) IN UNIFORM ELECTROSTATIC FIELD

Section by plane passing through axis of X of equipotential surfaces in neighborhood of sphere. The value of the potential of each surface is given in the figure.

The region between the inner cylinder and middle disk may be assumed to have an electrostatic field, the equipotential surfaces of which are cylinders concentric with the inner cylinder, and whose values are given by

$$V_1 = B \log_e r + A$$

The surface of separation between the two regions having potentials V_1 and V_0 will have for its equation,

$$r = e^{\frac{C - A + Dz}{B}}$$

$$= a \left(\frac{b}{a} \right)^{\frac{2z}{l}}$$

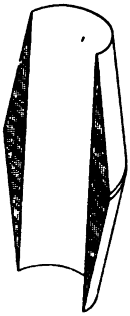


FIG. 3

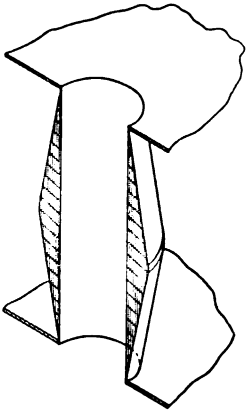


FIG. 4

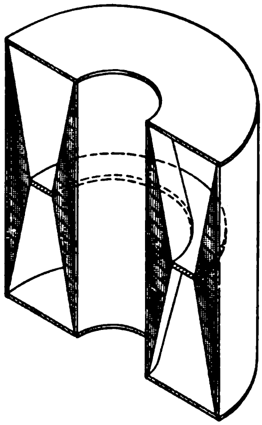


FIG. 5

where

$a = e^{\frac{C-A}{B}}$ = radius of hole in outer disk

b = radius of inner cylinder.

l = length of inner cylinder.

If the three disks are limited in diameter, the middle one being less than the other two, and if the region between the two outer disks is completely enclosed by an external cylinder extending from one to the other, the outer edge of the middle disk may be insulated from the external cylinder in a similar manner. These three examples are illustrated in Figs. 3, 4 and 5 respectively.

III. PRACTICAL APPLICATIONS—LIMITATIONS

In practical applications of this principle, the means for producing a potential distribution over a surface are limited. A finite number of steps must be used and the potentials must be applied to strips of metal of finite widths in such a way that the intervening surface between two adjacent strips shall have the proper potential at each point. However, with proper care in laying out the various parts, a fairly close approximation may be made to ideal conditions.

The practical application of the principle that at once suggests itself as being most suitable, is the insulation of high-voltage transformers. Accordingly, the problem of insulating high-voltage transformers, particularly such as are used for testing purposes, will first of all be considered. Application to line insulators will then be taken up and miscellaneous uses to which the principle may be adapted.

IV. CORE TYPE TRANSFORMERS

Before considering the application of the principle to the insulation of transformers, it will be well to consider the mechanical characteristics of the materials available for insulating transformers. Moulded material, on account of the large bulk required in high-voltage transformers, is probably out of the question. At present, the most suitable materials are obtainable in the form of cylinders and plates. The insulation of high-voltage transformers will therefore consist of structures of concentric cylinders and parallel plates of solid insulation interspersed with oil. The forms of electric field that are most suitable with such insulation structures, namely, the uniform field and the field of logarithmic potential, give also the best conditions of stress in the materials and are adapted to the natural form of the winding and core structure of transformers.

The simplest form of high-voltage transformer has one terminal connected to ground through the core and case and the other is brought out through a high potential bushing in the cover. Fig. 6 shows the diagram of connections for such a transformer designed in accordance with this principle. The high-tension winding of this transformer is made up of a number of discoidal-shaped coils, arranged and connected so that the potentials of the coils progressively decrease from the center coils outward. Thus, the coil marked, " terminal coil " has the highest potential, while that marked " ground coil " has the lowest potential.

Each coil is so placed that it lies on the equipotential surface, corresponding to its potential, of an assumed uniform field in the region included between the middle high-potential coils and the outer or low potential coils. The whole high tension winding thus assists in producing in the external region in close proximity to the windings, and in the part of the internal regions which are unoccupied by the cylindrical barriers, what substantially amounts to a uniform electric field.

The external surface of the cylindrical insulating structure which serves to insulate the core and low-tension winding from the high-tension winding is shaped according to the internal field of logarithmic potential and the external uniform field, as shown in the foregoing illustrations given in Section II. See Figs. 4 and 5. The potential distribution over the surface of this cylindrical structure is produced by connecting unclosed rings of tin foil on the insulating cylinders to the proper point of the high-tension winding. The top and bottom rings on each cylinder are connected together by a thin strip of copper, which also serves to connect an upper to a lower coil. Thus the ring and its connecting strip lie on the proper equipotential surface of the system, and therefore produce no disturbance in the electric field. Moreover, the ring on account of its width, helps to produce the proper potential at each point of the surface of the cylindrical barrier lying between it and the adjacent ring.

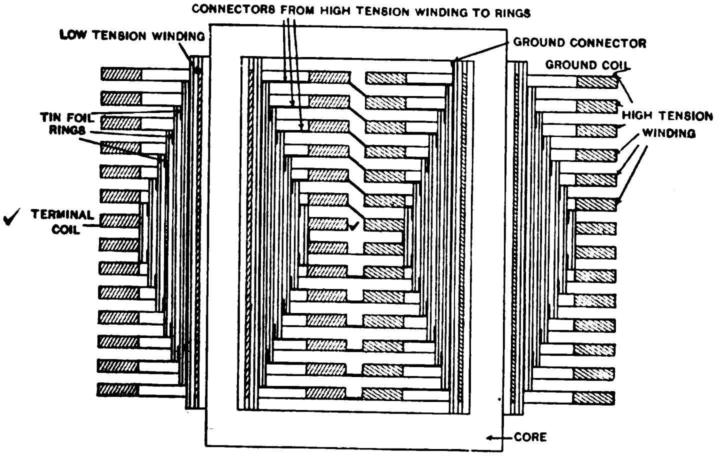


FIG. 6—INSULATION SCHEME FOR TRANSFORMER DESIGNED TO OPERATE WITH ONE END GROUNDED

The outlet bushing also is designed so that when in position the end of each conducting layer will lie on the equipotential surface of the system having the same potential, thereby producing the minimum disturbance. This outlet bushing is not shown in Fig. 6.

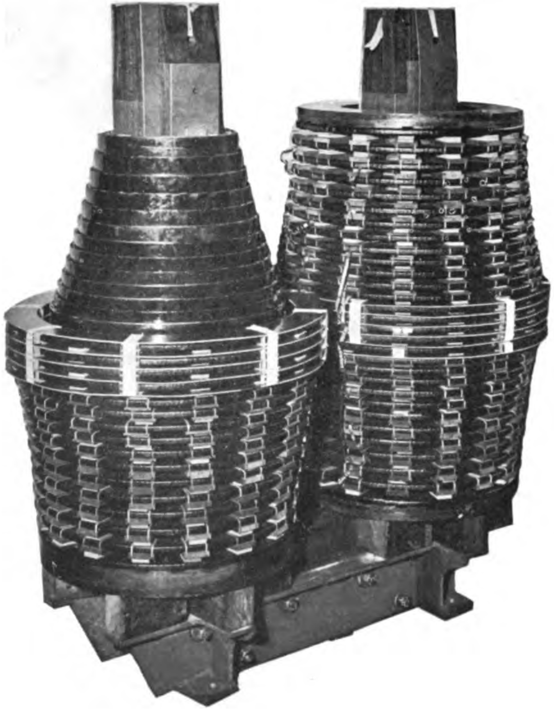
Fig. 7 shows a transformer built according to this scheme partly assembled. Fig. 8 shows the same transformer with coils and iron assembled, but without external barrier. Fig. 9 shows the transformer with external barrier partially assembled, and Fig. 10 shows the transformer complete in tank. No attempt was made to produce an artificial distribution of potential over the surface of the external barrier of this transformer which was made of fullerboard, on account of the impossibility of obtaining true cylindrical surfaces with such material. After this transformer was completed, it withstood successfully the following tests applied in succession:

High Tension Potential Above Ground By Ratio.	Time of Application.
400,000 volts	1 minute.
450,000 "	½ "
500,000 "	1 "
525,000 "	1 "
573,000 "	10 seconds

The potentials indicated by needle point spark gap were 35 per cent higher than given by ratio.

At a later date, the transformer was excited so as to give by ratio a potential of 623,000 volts effective above ground without the terminal in place.

The form of transformer next in degree of simplicity is designed to operate with the middle point of its high tension winding grounded. Instead of one transformer designed to operate in this manner being used, two transformers, like that already described, may be used, and while it is somewhat more costly to make two such transformers, there are advantages in having two units that can be used for testing independently. When two transformers are used in this way, the difference of potential obtainable with the same conditions of insulation stress is double that of one. Thus two transformers, each capable of producing 500,000 volts to ground when so combined, will be equivalent to a one million-volt transformer with the middle point grounded. The design of a transformer to operate with the middle point grounded may be made according to the scheme shown in Fig. 11.



FORTESCUE]

FIG. 7—TRANSFORMER PARTLY ASSEMBLED

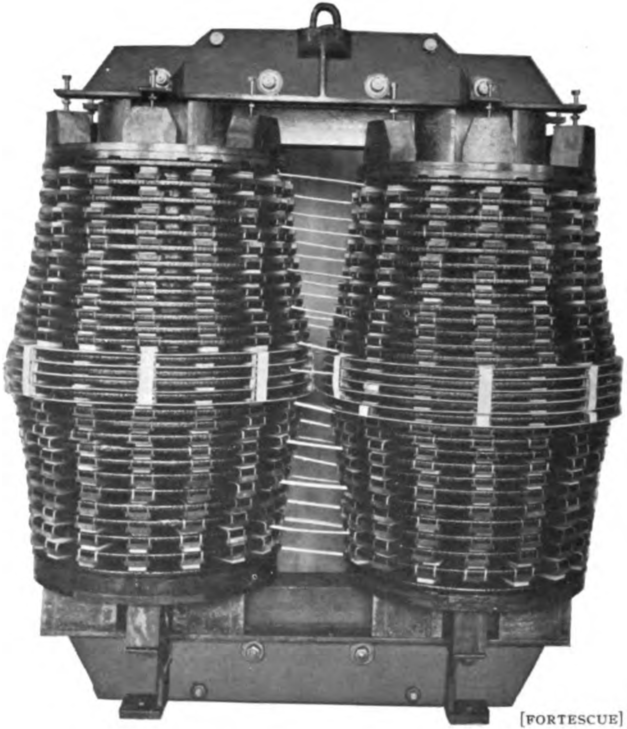


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FIG. 8—TRANSFORMER WITH EXTERNAL BARRIER REMOVED

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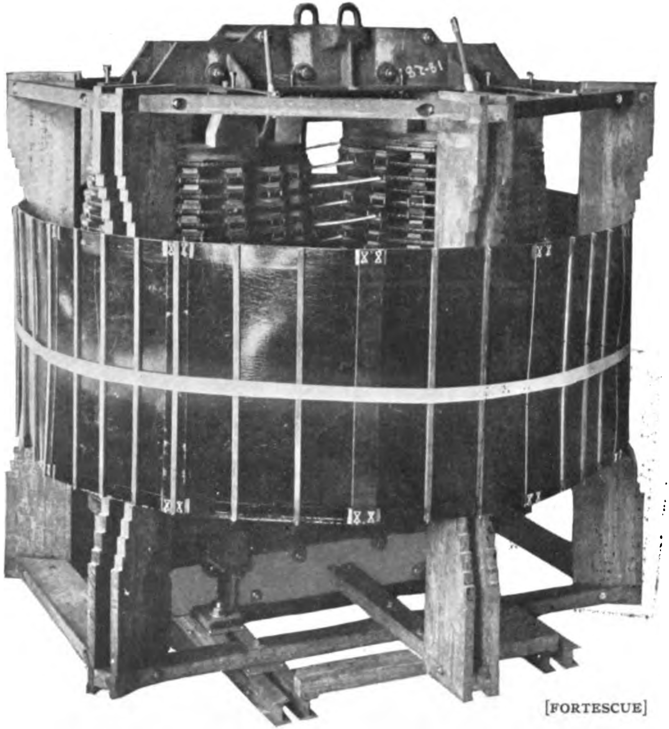
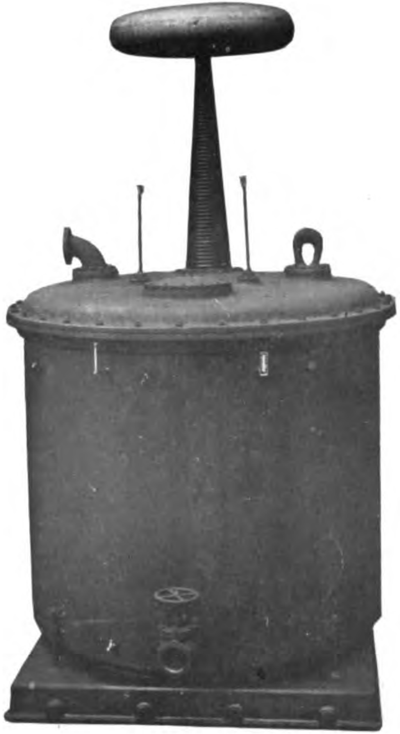
ASTOR, LENOX AND
TILDEN FOUNDATIONS



[FORTESCUE]

FIG 9—TRANSFORMER WITH EXTERNAL BARRIERS PARTIALLY ASSEMBLED



[FORTESCUE]

FIG. 10—TRANSFORMER COMPLETE IN TANK

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ASTOR, LENOX AND
TILDEN FOUNDATIONS

A transformer is sometimes required capable of operating with either end of the high tension winding grounded. A design for such a transformer may be made according to the scheme shown in Fig. 12. The insulating structure between the groups of coils on different legs may be made up of flat sheets, in which case the surface potential may be such as to give a uniform field. Instead of a structure of flat sheets, a cylindrical structure, completely surrounding the groups of coils on each leg, may be used, in which case, the proper potential distribution is such as will produce in the structure, a field of logarithmic potential. Besides acting as insulation between the two groups of coils, the cylindrical structure forms part of the insulation to ground, but it is hardly practicable on account of the high cost of insulating cylinders of very large diameter.

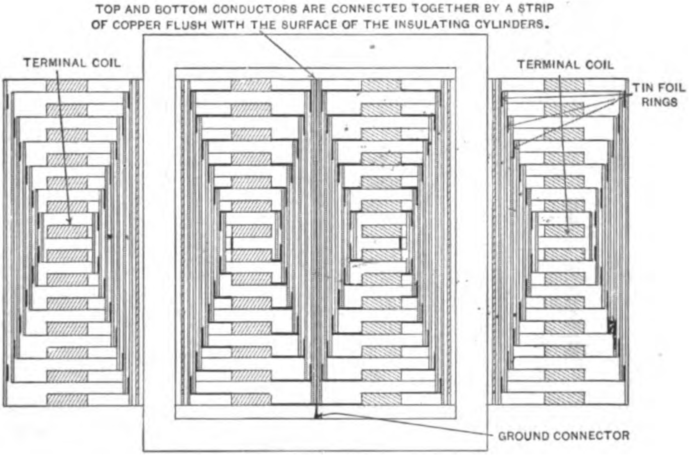

TOP AND BOTTOM CONDUCTORS ARE CONNECTED TOGETHER BY A STRIP OF COPPER FLUSH WITH THE SURFACE OF THE INSULATING CYLINDERS.
TERMINAL COIL
TERMINAL COIL
TIN FOIL RINGS
GROUND CONNECTOR

FIG. 11—INSULATION SCHEME AND COIL ARRANGEMENT FOR TRANSFORMER DESIGNED TO OPERATE WITH MIDDLE POINT GROUNDED

V. CORE TYPE TRANSFORMERS FOR POLYPHASE CIRCUITS

Conditions of operation on polyphase circuits are somewhat different from those on single phase circuits. A brief description will be given of the changes required to adapt the schemes for insulating transformers shown in the last section to polyphase circuits.

For grounded three-phase star systems, the scheme shown in Fig. 6 may be used unchanged. For ungrounded star systems this design may be modified by the addition of extra insulation between core and windings to protect against stresses due to one wire becoming grounded. The insulation included in the coil grouping, in this case, should be considered as a separate region, because external bodies may have their potentials changed relatively to the winding. Accordingly, the potentials of the windings themselves will also be raised or lowered relatively to external bodies. Therefore, to maintain the electric fields in the coil grouping and included insulating structures unchanged, it is necessary to consider all this space as a separate region. The intensity at each point within this region will then be independent of the potential of the coils relative to ground. For the region external to the winding included between the cylinder and coils of lowest potential of the winding system and the core, the proper potential distribution over the surface may be obtained by means of a system of concentric cylindrical condensers of equal capacity, varying in length by equal steps, according to the principle used in the condenser-type terminal. Fig. 13 shows a scheme of insulation for such a transformer.

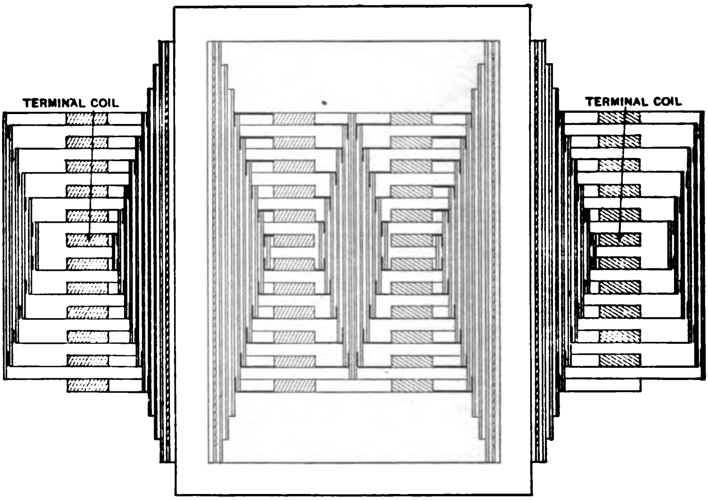


FIG. 12—INSULATION SCHEME FOR TRANSFORMER DESIGNED TO OPERATE WITH EITHER END GROUNDED

For delta connection, transformers may be a modification of design shown in Fig. 12, additional strength between windings and core being secured to take care of stresses when one winding becomes grounded.

Figs. 14 and 15 show polyphase transformers designed according to the principle.

VI. Shell Type Transformers

Figs. 16 and 17 show the arrangement and connections of the high and low-tension coils of a shell type transformer designed to operate with one end permanently grounded. Here the coils themselves correspond to the equipotential surfaces of one region, their potentials decreasing progressively from No. 1 to No. 9. In the regions included between the coils and iron, the surface potential is determined by the coils themselves, so as to produce approximately a uniform field. Fig. 16 shows a section through the middle of the group at right angles to the plane of the core laminations, while Fig. 17 shows a section of one side of the coils parallel to the plane of the laminations. A single group only has been shown. If more groups are used, each group may be wound in the same way, and insulated from the adjacent low tension winding and iron, according to the potential of the outer coils.

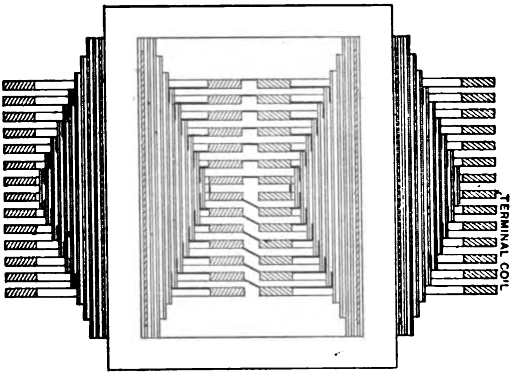


Fig. 13—Insulation Scheme for Transformer Designed to Operate on Star System with Ungrounded Neutral

A shell type transformer, designed to operate with its middle point grounded, may be made up of two groups connected as shown in Fig. 18, the inner coils of each group being the high potential coils, and the outer being connected to the iron and case and grounded.

For polyphase systems, modifications of the designs shown above may be used. These modifications are of the same nature as those required to adapt core type single-phase design to designs for operation on polyphase circuits, and need not be gone into any further.

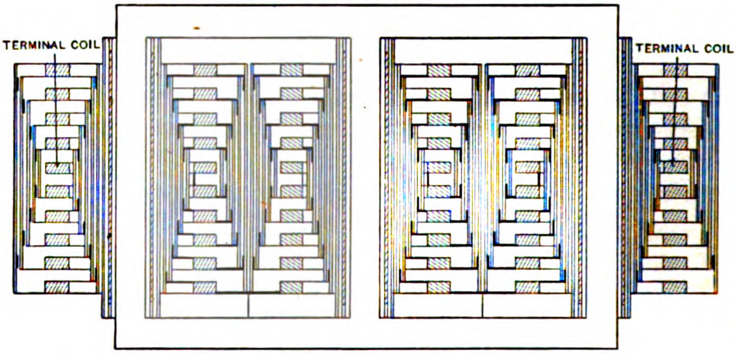


FIG. 14—THREE-PHASE TRANSFORMER TO OPERATE ON CIRCUIT WITH NEUTRAL POINT GROUNDED

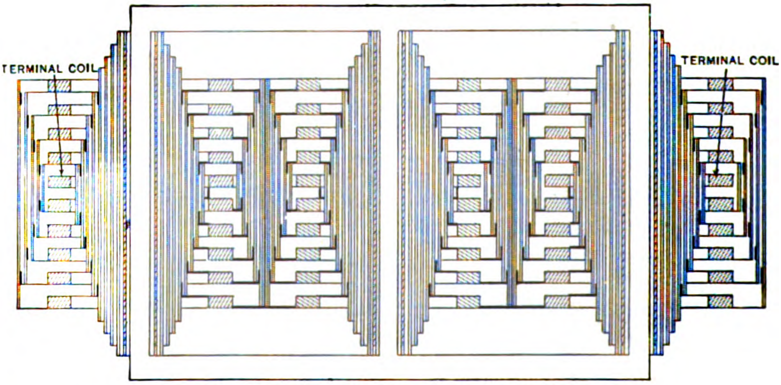


FIG. 15—THREE-PHASE TRANSFORMER DESIGNED TO OPERATE ON UNGROUNDED SYSTEM

VII. APPLICATION OF THE PRINCIPLE TO THE DESIGN OF OUTLET TERMINALS AND INSULATORS

In core type transformers, designed according to the principle, the outlet terminal forms part of the insulation system of the transformer, and must be designed in accordance with the same principle. One way of doing this would be to produce within the body of the terminal a logarithmic potential by means of rings of tin foil connected to the proper points of the transformer winding. This method, however, is not convenient. A better plan is to obtain the required surface potential distribution by means of a system of concentric condensers.

The condenser type terminal, as it is commonly called, affords a conspicuous example of the successful application of the principle stated in Section II of this paper. As commercially made, this terminal consists of a series system of concentric cylindrical condensers of equal capacity, so arranged that the ends of the conducting cylinders form, at the outer surfaces of the terminal, a potential distribution corresponding to that of a uniform field, the equipotential surfaces of which are at right angles to the axis of these cylinders. To conform therefore to the principle stated in Section II of this paper, the space external to the terminal must be bounded by two infinite parallel conducting planes perpendicular to the axis, one at the tip and the other at the end of the conducting cylinder of largest diameter, and connected to the conducting cylinders at these points. In practise, this condition is approximated by placing a disk-shaped conducting body at the end of the middle cylinder, and making the surface of the cover through which the terminal passes as free from projections and ridges as possible.

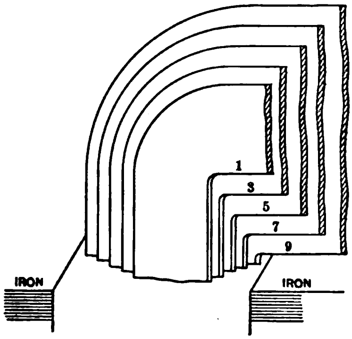


FIG. 16

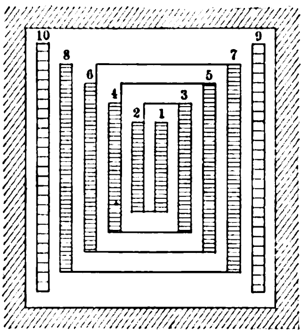


FIG. 17

A comparative test has been made on a terminal of this type, first with a small disk, and then with a large one, which illustrates in a remarkable way the importance of the proper application of the principle. The terminal when tested with a small disk, at a potential above ground of 300,000 volts, showed signs of corona, which extended to the rings at the edges of the tin foil cylinders at 350,000 volts. At 400,000 volts, the whole terminal was lit up with corona. It was not found advisable to raise the voltage above 420,000 volts for fear of rupturing the terminal. The small disk was then replaced by a large one five ft. (1.52 m.) in diameter and one ft. (0.304 m.) thick with semi-circular edges. With this disk the terminal showed no signs of corona up to 573,000 volts. These potentials are those obtained by ratio. By a needle spark gap, the values indicated were 35 per cent higher.

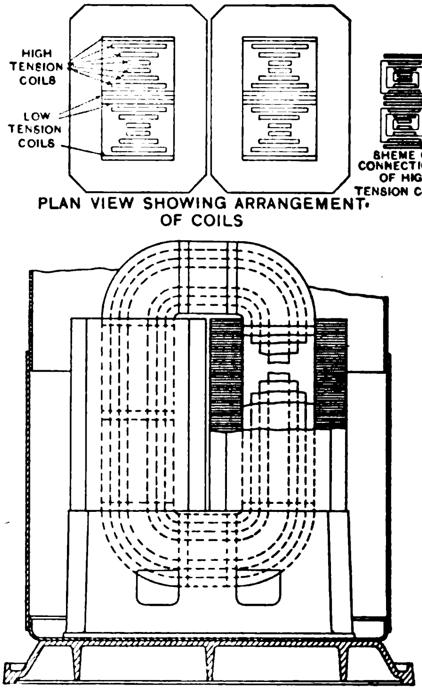
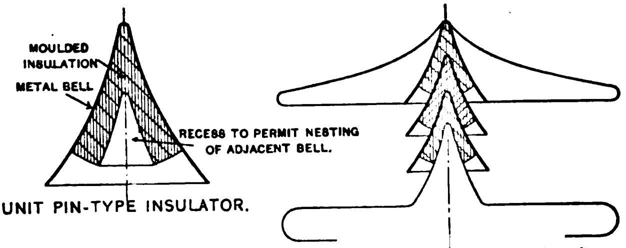

HIGH TENSION COILS
LOW TENSION COILS
SHEME OF CONNECTIONS OF HIGH TENSION COILS
PLAN VIEW SHOWING ARRANGEMENT OF COILS

Fig. 18—Shell-Type Transformer Designed to Operate with Middle Point Grounded

There are other ways of constructing a terminal, depending upon the same principle. For example, instead of using a system of concentric cylindrical condensers, a system of parallel disk condensers of equal capacity might be used, the diameter of the disks being such that the distribution of potential over the surface of the internal region of the terminal will correspond to a logarithmic potential, with proper relations between the inside conducting cylinder and the inside edge of the outer disk. The intensity within the terminal may be limited to any assigned value. A terminal designed in this manner would occupy more space than the condenser type terminal, but might have advantages where it is desirable to make the overall length as short as possible.

A transmission line insulator consists of a system of condensers in series. To obtain an equal division of potential difference between insulators, is not the only requirement of a successful design. This condition may actually be obtained, and yet the system of insulators will break down at a very much lower potential difference than the sum of the breakdown strengths of each insulator. The strength of the system may be increased by applying the principle stated in this paper. Accordingly, if the units of which the insulator is composed are equally spaced, and have each the same capacity, the high- and low-potential conducting surfaces which are insulated from each other by the insulator should be so designed as to give as nearly as practicable a uniform field corresponding to the potential distribution at the outer surface of the insulator. For example, Fig. 19 illustrates an element of an insulator, which consists of a metal bell, so designed that it may be used as the electrode of the adjacent insulator. A dielectric compound is moulded into the above mentioned bell, so that it will have a recess for the adjacent bell to nest into. The surface of the dielectric, which is intercepted between two adjacent bells, is moulded so as to conform to the lines of force of the electric field between the two adjacent bells. A nest of these may be used as a high-voltage insulator, and each insulator will take up approximately an equal share of the differ-



UNIT PIN-TYPE INSULATOR.

NEST OF PIN-TYPE INSULATORS.

FIG. 19

ence of potential, but in order to obtain the highest efficiency from the insulator, an arrangement of parallel discoidal-shaped electrodes, like those shown in Fig. 19, must be used. The external field will then be substantially uniform, and agree with the division of potential between the individual insulators. The efficiency of the combination is thereby increased in exactly the same way that the efficiency of a condenser type terminal as an insulator was increased by the addition of the large disk, namely, because it completed the surface distribution of the region surrounding the terminal in accordance with the principle.

A unit insulator, made according to the above plan, conforms to the law of similar fields. Thus, if the dimensions are doubled, the breakdown voltage is doubled. The cost of an insulator of this kind will vary approximately as the cube of the voltage. If, by some such method as that outlined in the last paragraph, the efficiency of a nest of insulators can be made to equal that of each individual unit, and if this can be done at a reasonable cost, then the cost of an insulator of this type will vary directly with the voltage for which it is designed. It is therefore obvious that an insulator, consisting of a nest of small insulators, would cost less than a large single insulator designed for the same voltage.

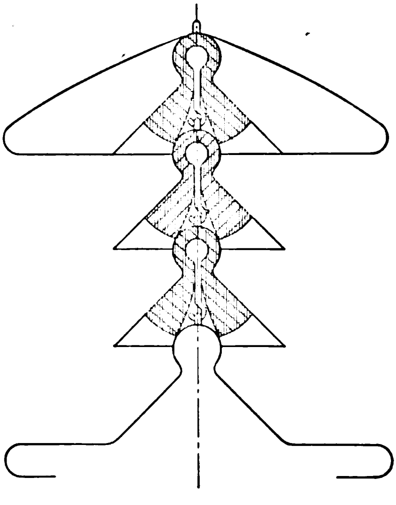


FIG. 20

The principle may be applied to suspension type insulators, also, as shown in Fig. 20. Other types of insulators besides those shown may also be assisted by the application of this principle, but the advantage to be gained is not so evident as in the type shown.

VIII. MISCELLANEOUS APPLICATIONS

The well known principle of the guard ring is a particular case of the principle stated in Section II, and so also is the method of protecting instruments by means of grounded metallic coverings. The principles gives the method by which a given electric field may be maintained constant within an enclosed region, independent of the influence of external bodies. It may therefore be used to protect systems of charged bodies from the influence of other bodies. There seem to be many possible applications of the principle in high-voltage investigations.

IX. CONCLUSIONS

The principle stated in Section II of this paper has been used to insulate a high-voltage transformer. This transformer has been used to produce a potential above ground which the author believes is the highest yet obtained by electrical apparatus. The principle is capable of wide application, and seems to afford a solution of some of the most perplexing problems confronting electrical engineers.

DISCUSSION ON "NOTES ON UNDERGROUND CONDUITS AND CABLES" (MOSMAN), BOSTON, MASS., MAY 15, 1912. (SEE PROCEEDINGS FOR MAY, 1912.)

(Subject to final revision for the Transactions.)

A. E. Kennelly: This paper manifestly embodies a large amount of valuable experimental work. It is work, as has been stated, done under very trying conditions, and we are all the more indebted to those who have done the work on that account. We have, it is true, known but little concerning the heating conditions inside ducts, although we know fairly well the heating conditions around a single cable of known dimensions buried at a given depth in the ordinary soil. I do not mean to say that we ought to be content with the knowledge which we have in that direction, but at least we have some knowledge.

The data obtained are interesting. This underground system, as shown in Fig. 1, was largely an "over-ground" system. Nevertheless, there is one section that does seem to have been truly an underground system, although just how deep underground I have not seen it stated. I think it would be important if some measurement could be given of that depth. The data led to the showing, as Mr. Mosman has said, of what this particular conduit will stand without overheating the cables it contains; and in a general way, of course, what is true of a duct in the conditions here might be acceptable in general. But it is very important, it seems to me, that the data collected here at so much time and expense should be made available for general purposes, beside being applicable to this specific case and this particular number of ducts; and I think the measurements made here are applicable to such a generalisation.

If we take a conductor that is cylindrical and suppose it to be buried in water so as to keep its temperature at the surface down to a known amount, and then send a uniform current density all through the cable—which of course would not be possible with a large conductor and alternating current—the hottest place would be in the center and the temperature gradient would be lowest, naturally, at the very outside or the skin. That has been worked out. In a cable of 1,000,000 cir. mils. the difference of temperature at the center and at the skin is a small fraction of a deg. cent., with ordinary loading, so that with copper the difference of temperature that one would get is quite negligible from an engineering standpoint; but if we take a large cylinder of very poor thermal conducting material and moderately good electrical conducting material, the difference of temperature that we can get between the center and the surface is very material; and large conduits, if they were made circular and then filled up like the cross-section of a watertube boiler, might be considered as having moderate electric conductance, together with a very considerable thermal resistance. This is made up of the cement and the fibre, modified by the presence of the cables. Electric conductance is supplied by the cables themselves. The way such a test would be naturally made is in the manner recorded here. Of course it assumes a circular conduit. We do not get them circular—we get them square. That makes the computation very hard instead of comparatively simple. Nevertheless, if we take a square conduit, as in this case, and make the equivalent circle, I do not like to say what the error would be, but I do not think it would be very great and the computation would be approximate for engineering purposes. So that this gives us data from which we can get the average thermal conductance per foot, provided the duct surface has a known temperature. If it has the same temperature all the way round and it is known, then, knowing the temperature at any distance from the center, we can compute that and apply it to any duct for which the temperature on the outside can be specified. That has to be done, of course, not only for a duct of cement or fibre, but for a duct of other materials; on one where the relative dimensions of the tube differ. It would only be necessary, probably, to make similar tests upon a few feet of duct of different materials.

One very interesting thing brought out is that the ends make such a tremendous difference. That is surprising to me and I should not have supposed that the drop of temperature at the ends of the duct would be anything like as great as shown by the curve in Fig. 15. You can see the gradients starting at the middle. This shows how much heat may be carried out of a duct with stationary air by thermal conduction—apparently through the sheath—and how carefully the measurements should be made to avoid that effect in making such tests as these I am speaking of and as are detailed in connection with Figs. 16 and 17. An inference drawn from the paper is that one can, by means of forced draft, make a duct workable that would be unworkable otherwise.

The above result is very useful, but I think it would be a very expensive method to maintain except under good local conditions. It seems to me that the next best arrangement would be to make a hollow conduit, that is, if we have a square conduit we could build it up at the sides, and leave the interior part hollow. But in all cases it should be put down underground. A hole in the ground is much cooler than a hole in the air, for any duct or cable. One would naturally suppose that a duct which was surrounded on all sides by air would be kept cooler than a duct buried in the ground, especially in the winter time, but I think all theory and practical evidence is against that being true. It is best to have a conduit underground. Of course I am speaking of a hollow conduit. If you are going to have a conduit full, you would put the lightly loaded members in the center and protect them by the more heavily loaded members, so that the temperature might be very flat in the center owing to the small amount of current. The data given in Figs. 16 and 17 seem to me to be excellent for the purpose of determining the average thermal resistance, on the assumption that the conduit is of square cross-section.

L. L. Elden: As Mr. Mosman has stated, the installation of conduit and cables which has been described in his paper does not represent commercial conditions usually present in central station systems. It should further be noted that the author's conclusions with regard to carrying capacity of cables are not applicable to central station operations.

Experience in conduit constructions indicates that it is inadvisable to install more than 12 to 16 ducts in any single group entering a manhole, with a strong preference for the smaller number in city construction. With moderate size conduit lines it becomes possible to protect cables from injury due to burnouts which may occur from time to time, more effectually than is possible in manholes where a large number of cables are concentrated.

When considering the carrying capacities of different classes of cables, recognition should be given the seasonal changes and climatic conditions governing temperatures in each part of the country under consideration. In this particular latitude central station operations have to contend with maximum load periods averaging approximately one hour, therefore it is possible to apply more liberal ratings to cables or other apparatus used in such service than would be the case in localities where higher temperatures are normally experienced.

If we consider the ordinary city conduit, it will be found that, owing to the variety in size and types of cable ordinarily used, the radiation of heat from heavily loaded cables is materially assisted, or at any rate not impeded, by the other cables in the same conduit, many of which do not suffer any rise in temperature from their own currents owing to their small values.

In enumerating these cables, low-tension a-c. and d-c. feeders and transmission lines are those which suffer the largest temperature rises, and, therefore, need to be placed in the most favorable positions to effect easy radiation, while cables used for primaries, low-tension a-c. or d-c. mains, neutrals, pressure wires and series arc lighting circuits rarely need to be considered as far as radiation of internal heat is concerned, thereby permitting their installation in such locations in conduits as may be convenient.

When placing cables in conduits, it is advisable to place heavily loaded cables in the outside ducts along the sides and at the top of conduits, leaving the smaller and cooler cables to occupy the bottom and central positions.

Referring to commercial practise in the design of conduits, it usually is unnecessary to make elaborate calculations on the radiation of heat from cables in conduits of medium size, for the reasons above stated. However, at station exits where large numbers of cables are necessarily grouped together, care should be exercised to properly provide for any excess temperatures which may be developed, particularly in large direct-current distribution systems. The dissipation of energy per duct-foot which the author has suggested as being allowable is many times exceeded in regular service on short hour peaks, in fact four times the limit referred to by Mr. Mosman is regularly attained in certain locations without detriment to the cable. After looking through a number of temperature readings taken on cables in the Boston Edison system in the past, it seemed advisable to obtain some additional records of similar character today, and these are presented as of possible interest.

1. Manhole at entrance to substation connecting with a 12-duct conduit. Six 1,000,000-cir. mil d-c. cables in conduit.
Cable tested after carrying 700 amperes six hours.
Manhole temperature, 22 deg. cent.; cable temperature, 43 deg. cent.; rise, 21 deg. cent.

2. Manhole in street connecting a 4-duct conduit. One 1,000,000-cir. mil. cable in conduit.
Cable tested after carrying 800 amperes four hours.
Manhole temperature, 18 deg. cent.; cable temperature, 38 deg. cent.; rise, 20 deg. cent.

3. Manhole in street connecting a 24-duct conduit. Six 4/0 three-conductor transmission cables and miscellaneous cables in conduit.
One 4/0 three-conductor cable tested after carrying 210 amperes 8 hours.
Manhole temperature, 15 deg. cent.; cable temperature, 27 deg. cent.; rise, 12 deg. cent.

4. Manhole in street connecting a 9-duct conduit. One 1/0 three-conductor transmission cable and miscellaneous series arc cables in conduit.

One 1/0 three-conductor transmission cable tested after five hours' run at 100 amperes.
Manhole temperature, 15 deg. cent.; cable temperature, 20 deg. cent.; rise, 5 deg. cent.

5. Temperatures taken at end of conduit inside a station building.
Room temperature, 21 deg. cent.; cable temperature (average), 35 deg. cent.; rise, 14 deg. cent.

6. Tests in large conduit leaving the substation in this particular building in a conduit line consisting of 45 ducts each occupied by one 1,000,000-cir. mil d-c. cable. Total current leaving the station 7000 amperes.
Manhole temperature, 20 deg. cent. Tests on various cables after carrying the following specified loads four to six hours:

1,000,000-cir. mil d-c. cable, 500 amperes 23 deg. cent. rise 3 deg. cent.
" " " " " 700 " 30 " " " 7 " "
" " " " " 200 " 21½ " " " 1½ " "

Variations in temperature were noted among cables carrying the same loads, due to their location in the conduit with reference to the loaded cables, and to the outside faces of conduit.

7. Temperature of a 1,000,000-cir. mil d-c. cable carrying 800 amperes for a long period, in location not affected by other cable, showed a rise of 40 deg. cent.

8. Temperature of 1,000,000-cir. mil concentric cable used for d-c.

feeders and operated at 1000 amperes showed approximately the following increase in temperature:

	1st hour temperature rise	2nd hour temperature rise	3rd hour temperature rise
Sheath..........	10 deg. cent.	25 deg. cent.	40 deg. cent.
Outer conductor...	20 " "	40 " "	55 " "
Inner conductor..	21 " "	42 " "	60 " "

While this type of cable is not as well adapted for continuous heavy duty as are single-conductor cables, the economies which it effects in duct space and its ability to carry heavy loads from two to three hours make it eminently satisfactory for central station systems.

9. Temperature of 4/0 three-conductor 15,000-volt cable operated at 250 amperes attained a rise of 47 deg. cent. after two hours, and at 300 amperes rise 63 deg. cent.

These tests were made on individual cables in conduits with other cables and indicate the average conditions which would obtain in the ordinary operations of the system.

In connection with these tests it has been demonstrated that the winter temperatures in manholes closely approximate 10 deg. cent., while summer temperatures reach 25 deg. cent., a condition particularly favorable in connection with the operation of a cable system under maximum load conditions as they occur in this latitude.

From every point of view the method of designating the carrying capacity of cables by temperature rise is misleading in effect, as full value or use of cables cannot be attained by such methods. It is contended that a determination of the maximum allowable cable temperature should be the true method of rating a cable, thereby leaving it possible for the operators of distributing systems to work cables at higher kw. capacities in winter than in summer. For instance, repeated tests on 1,000,000-cir. mil. and three-conductor cables as between winter and summer conditions show that the winter ratings may properly exceed the summer ratings of such cables by 10 to 15 per cent while attaining the same maximum temperature.

The suggestion is made by the author that a 50 deg. cent. rise is good practise for paper-insulated cable for high-tension work. Assuming that this rise is to be calculated for a base of 20 deg. cent., a maximum temperature of 70 deg. cent. would result, as compared with 73 deg. cent. in English and European practise. As the average temperature in England is lower than in Massachusetts, the advantage of the maximum temperature method of rating is obvious.

Referring to foreign cables, it should be noted that the impregnating compounds used abroad are somewhat different in composition from those with which we are familiar, in that they are adapted for operation at higher temperatures.

Mr. Mosman has spoken of bonding methods and troubles resulting from sheath currents. With 1,000,000-cir. mil. lead covered cables used for alternating-current service, sheath currents are developed which require serious attention, although such installations are rarely met with in commercial service, for obvious reasons.

Primary or secondary a-c. mains using single-conductor cables larger than 350,000 cir. mils are rather met with in central station systems, and owing to the distances covered it rarely occurs that such cables are loaded to exceed two-thirds their maximum carrying capacity, under which conditions the sheath currents do not exceed 10 per cent of the line current, an amount of current easily cared for by proper bonding. Wherever possible this evil may be avoided by using multiple-conductor cables for a-c. distribution.

Bonding of cable systems should receive serious attention by all operating companies, first to avoid damage to cable sheath from electrolysis, and secondly to avoid sparking between sheaths.

Good practise indicates that all cables in manholes should be substantially bonded together and grounded at frequent intervals, and in some cases special conditions may indicate the desirability of bonding to railway return systems to avoid electrolytic troubles.

In transmission systems operating with a grounded neutral, it is particularly desirable that all transmission cables be securely bonded together and in some locations securely grounded in order to insure a path of low resistance for fault currents in the event of cable failures.

The lack of definite knowledge of the relative radiating values of the different forms of ducts, when installed in groups of various shapes and sizes, and in different soils at varying depths, under conditions regularly met with in practise, is regrettable, and studies on this subject would be of great value.

The radiating value of fibre duct is practically an unknown factor, although its advantages in other directions are well known, particularly in the assistance it affords in insulating cable sheaths from ground currents in locations where conditions are favorable and where such construction affords relief from electrolysis.

William L. Puffer: Referring to Dr. Kennelly's idea of hollow construction, I believe that the proper way of considering this whole matter is to take into consideration what lies outside the surface of the conduit. The heat is carried away by the earth. You have a certain circumference of the duct line going through the earth. The question is, how fast the earth can take heat away from that. Consider everything inside the conduit line as a sort of composite device which is producing heat. Note Fig. 17, bearing in mind that the direction spoken of is diagonal, not horizontal or longitudinal to the surface of the conduit. If you will notice the numbering on these ducts, you will see that these are given diagonally and not from duct to duct measured from the outside inward. Also note that it would be better if you drew a horizontal reference line at about the figure 20, in Fig. 17, representing the temperature of the earth, which has been referred to as about 20 deg. cent. You will notice then that your curve has a different appearance as you get inside the duct line, the temperature rising enormously. In Fig. 18, if you will draw that horizontal line through the 20-deg. mark you will notice that the first curve, for duct No. 1, shows a comparatively small rise in temperature. Then as you go diagonally into that duct line the temperature is rising enormously.

Referring to the remarks on the next to the last page, concerning the data given in Fig. 24, the copper carrying capacity is interesting. A loss of 2.5 watts per foot (30.5 cm.) or 475 amperes on the 1,000,000-cir. mil. cable corresponds to 2100 mils per ampere or about 600 amperes per sq. in. (6.45 sq. cm.), which you see is comparatively low density. Then the four watts per ft. corresponds to about 1700 cir. mils per ampere or a density of approximately 775 amperes to the sq. in. (6.45 sq. cm.). If you will turn to Figs. 25, 26 and 27 and notice the way in which these temperature rises are made up, beginning at the top at the extreme right of the curves, you will notice that there is a very little temperature difference between the copper and the sheath—something like three or four degrees. That compares very well with measurements which I have taken by a very refined method, where there is no room for query. The data are unusually correct for a duct line in service. There is a big difference between the temperatures of the sheath and the air in the duct. I think that is due to the method of measurement. If there is any way of producing artificial cooling so that you can eliminate a large part of the difference in temperature between the sheath and the outside air or ground, there will be a chance to spend money to great advantage. I have suggested, and this suggestion I do not claim is original, that the way to do with a line that is going to run a great deal of current for a long time is to see that the ducts are full of water. If you ever try heating water you will find that it takes a great many watts per foot before you can raise the temperature, and if you put water through these ducts you will find that the carrying capacity will go up enormously. That same idea is possible in measurements. I imagine that the temperature measurements were made up from the resistance of iron wire which had been calibrated externally, then pulled into the ducts and the drop measured. You will notice that would give two readings because of the fact that the wire is cooled by the external body of the duct in which it is resting, so you would get a lower indication than you would have if the wire were in position during the calibration, so that these temperatures, I think, should be even higher. I think the results have been understated rather than overstated, due to that possible error.

If you will look up Fig. 8 and observe the carrying capacity of the different ducts making up this 9 by 9 line, you will realize that substantially 40 per cent of the ducts are not loaded anywhere near their capacity so that the figures we read in here really have to do with a duct line which has only three tubes, being cooled on one side by a temperature which is comparatively low, 36 to 22 deg. cent., and on the other side a temperature of something like 25 or 26 deg.. cent. So the information in this part of the paper should not be confused with that which is given a little later on. I think that it would have been well to include a sketch showing the temperatures in the duct which was actually underground.

I do not see anything to criticise unfavorably in the paper, and I know very well from experience how hard it is to make any sort of tests that will plot anywhere near a straight or curved line under such conditions as those under which this has to be done; and the fact that the investigators got any curve line at all shows to my mind that they should receive a great deal of credit for doing this work.

William Clark: In reference to Professor Puffer's statement, regarding the calibration of the test wires, the sample of wire was wound on a spool and immersed in oil contained in a tank which was also immersed in water, the temperature of which could be controlled, so that we had a direct contact with the cooling medium as nearly as possible approximating the result obtained in the duct, although in the duct there was but a small contact between the iron wire and the fibre.

In reply to Dr. Kennelly's question concerning the earth's surface and the top of the conduit line, no measurements were made but it is my impression that the concrete envelope was 18 in. or 2 ft. (45 to 60 cm.) below the surface of the earth.

E. N. Lake: These experiments show rather conclusively the influence of thermal conductance and radiating surfaces upon temperature rises. In this connection, I think it will be granted that a clay material has a better conductance than the fibrous material. The square duct, as has been suggested by one of the previous speakers, has a larger radiating surface. That also gives a slightly larger surrounding medium of air. So I believe the question of the relative advantages of round fibre duct as against square clay duct is worthy of very careful consideration and a good deal of study on the part of distribution engineers. There are a number of large systems in this country that have, after a considerable amount of experimentation, adopted the single, square, clay duct.

In the matter of manhole protection to cables, several companies have used a little different method from that suggested by Mr. Mosman, and that is, to support the cables in the manholes not upon metal racks but upon some form of shelving, and to protect them one from the other, so as to isolate the cables in the case of burn-outs, by the same class of material that is used throughout the length of the duct, namely, vitrified clay, using for this purpose split sections.

Fig. 15 shows very strikingly the relation of radiation and conductance. I would like to suggest that perhaps the temperatures as given by Mr. Elden were temperatures that would correspond to the temperature conditions of cables at the manholes.

As to the matter of conduit construction, a subdivision of duct line is usually, although not always, possible—a construction which carries through the center of the duct section a dividing wall of the conduit. This has been used to very good advantage—a construction which has been called duplex construction—using a maximum single section of 12 or 16 ducts, but a total section of 24 or 32, carrying the opposite section in the other side of the manhole. This has been done primarily to accomplish, as nearly as possible, perfect separation of the cables, so that trouble in one conductor will not be transmitted to the entire group in one manhole.

One of the preceding speakers mentioned the use of water as a medium for surrounding the cables. I recall a case of serious trouble that at the time, without giving very much thought to it, we attributed to the presence of water in the ducts and manholes. There were some forty-two 600-volt railway cables in a conduit line filled with water, covering the entire number of cables. What is called by distribution men a " slow burn-out " occurred. It was so slow that the men could keep the circuit breakers in at the station, working at it industriously. After a couple of hours of this kind of operation, between one and three o'clock in the morning, it was discovered that all 42 of these cables were burned off under the water. I do not know whether it would be possible for that to occur under any other conditions or not, but it was one of the most unusual burn-outs that has ever come to my attention.

G. A. Burnham: I can perhaps answer the question Dr. Kennelly brought up about Fig. 15. If you compare Fig. 15 with Fig. 12 you will note that the variation in temperature in both curves, that is, the difference between the minimum of one curve and the maximum of the same curve, is practically the same; it is approximately 25 deg. cent. between the low point and the high point. The reason for the curve in Fig. 15 dropping off so abruptly on the right hand side is that that manhole, if I remember correctly, was open to the air on one side. The temperature in manhole No. 9, I think, was considerably lower than manhole No. 4. Now in curve No. 12 of manholes 3 and 4, we had a 10-in. (25-cm.) vent pipe in No. 4, and the temperature was very much higher than in No. 3 due to direction of air current. I think the temperatures which Mr. Elden mentioned were at the mouths of the manholes. Although his temperatures are rather low, they seem to bear out the conclusions which have been arrived at in this paper, that the temperatures within the duct are considerably higher than is indicated at the mouth of the manhole, because it does not appear that there can be a great deal of circulation and natural ventilation in a long conduit line; that seems to be practically proved by Fig. 15. That shows practically no ventilation, no action of air from one end to the other, as a contrast to Fig. 12. In Fig. 12 the direction of air is from right to left, from manhole No. 3 to manhole No. 4, because the air sweeping down through the ducts carries the heat with it.

Curve 1 in Fig. 23 seems to indicate that the contact resistance and resistance of the ammeter coil was practically 60 per cent of the total resistance of the lead sheath.

That same ammeter, with the same method of bonding, was applied to the spinning room circuits, and those were approximately 275 ft. (84 m.) and one would naturally expect that curve 2 of Fig. 23 showing the sheath currents in the spinning room circuit, would be much higher than it is, because the resistance per foot of the lead sheath, including the contact resistance of the bonds and the resistance of the ammeter coil, would be considerably higher than would be the case in the experimental cable, and with the same current density there would be the same flux and induced voltage per foot. So one would expect that curve 2 would be a great deal higher than shown, if the readings on curve 1 are correct.

The point brought up by Professor Puffer, about the measurements of the temperatures not being taken in a horizontal direction, is interesting. Of the two curves which are plotted in Fig. 17, one is a curve starting at the upper left hand corner of the conduit line and running at an angle of 45 deg. downward, and the other is starting at the left hand bottom corner of the conduit and running 45 deg. upward, and the two curves practically coincide, so it seems to me that is a fairly average condition.

David Harrington: I wish to discuss the practical side of the question—what we are going to do about it. There does not seem to be much doubt that there is a certain amount of heating through the ducts, and it seems very natural that there should be, under the circumstances. I am somewhat skeptical in regard to Dr. Kennelly's idea of a central duct. I should be rather doubtful about the efficacy of a duct filled with still air or doing much in the way of conducting away the heat. I think it is doubtful whether still material of that kind, either air or water, would for any considerable time take care of the heat; but I do believe that the day is coming and is perhaps nearer than we think, when the central station man can control the conditions in the manholes and in the conduits.

People have fought rather shy of this question. When a pole line needs anything done to it or there is any difficulty, they get after it and find out what is the matter with it, and from time to time they inspect the system; and also the engine is oiled, nowadays, so that it will run properly; but an underground conduit is put into the ground, the manhole is built, and they say "Let it go and it will take care of itself." I do not believe that attitude is going to be mantained for a great length of time, and I believe we can control the conditions of the manhole and of the ducts. Without going into details, I believe that with a forced draft the air could be controlled at practically whatever temperature may be desired, and perhaps at an expense which would be thoroughly warranted by the saving received. Moreover, the advantage of controlling the manholes and ducts by a draft of air would entirely take away the problem which we have from gas in our manholes. That would be taken care of at the same time as the temperature. I doubt if there is very much difference for a long space of time in the temperature of the ground immediately outside the duct. I think that under ordinary conditions the ground immediately adjacent to the ducts becomes of the same temperature as the ducts and is somewhat slow in dissipating the heat. I think we could get a very much quicker and more satisfactory regulation by moving air than we would by the still earth, still water or air. This method I do not think is so difficult as people believe. In the first place the large conduits which would naturally be most affected by the heat are in general rather close to the station and they would be more easily reached than a smaller duct, which would not need ventilation so much, perhaps. Some twenty years ago in New York the condition of the conduits was regulated by air pressure from the station, and that was at a considerable distance from the station. It was found not be be an expensive or a difficult thing to do, and a very simple method of maintaining air pressure was found efficacious. Of course the parts of the transmission lines which would naturally carry the heavy current are generally in small conduits and probably would not be as much affected as the larger conduits. It is my opinion that possibly attending to the condition of the conduits and the air in them and regulating that might be a simpler matter than to try to regulate the cables and adapt them to the conditions which we find in the conduits.

George W. Palmer, Jr.: This paper shows that there has been a great deal of care taken in getting it into shape. There is very little literature extant on the subject of the limitation of the carrying capacity of cables due to the manner in which the heat is radiated from the cables, and any contribution to this subject is to be welcomed.

It is evident that operating companies which are now using or have been using overhead conductors, and have been accustomed to overload them heavily, have got to modify their practise very materially when they come to put the conductors into underground conduits. Now we are not going to be able to work these conductors at the same current density when we get them underground. I would have been glad to see some data given in the paper on the performance of cables in tile duct, which has been longer and more extensively in use than the fibre duct, which has come into use within the last few years.

I think it is evident from what has been said that something can be accomplished where a conduit has a large number of ducts, in making it of the shape, so far as may be, to give the most favorable radiation. I note that resistance to puncture as given by the author does not decrease for paper as rapidly as it does for cambric, and that is interesting.

We have tried to keep our conduits dry. If water gets into a manhole, we drain it, and we lay our ducts always with such a pitch that there will be no water left in them. I should hesitate for a long time before filling up the ducts with water. We know that the presence of water increases certain troubles in our cable sheaths and makes them much more likely to fail. I am somewhat surprised to see the values which are given for sheath currents. I note that on 1,000,000-cir. mil cable carrying 500 amperes the author gives 175 amperes. This is somewhat larger than I should have supposed the value to be. The safe carrying capacity, the author evidently thinks, from the conclusions he draws from his data, is 2.5 watts loss per foot (30.5 cm.) of duct, corresponding to a load of 475 amperes on a 1,000,000-cir mil cable. It seems to me that if we are not going to be able to work our cables at any higher current density than that, we must find some cheaper metal than copper to use. At the end of the paper the author comments about these sheath currents, which raises the question of whether or not it is more desirable that all the phases of the circuit should be included in one cable. We found in our own practise a number of cases where electrolysis occurred in single-conductor a-c. cable with lead sheath. As the cable happened to belong to somebody else and was laid somewhere near a street railway track, the railway company was immediately accused of damaging the cable, but I think the company was able to convince the owners of the cable that the cause was elsewhere. In regard to the protection of the cable in the manholes with silicate of soda, while we have never used that, I understand it is of no value where there is dampness present in manholes.

William L. Puffer: This paper, we must remember, treats of a 9 by 9 duct conduit, run with alternating current, presumably entirely ungrounded. Two of those who have taken part in the discussion have compared with it certain systems which every one thinks at times are grounded, and the comparison is not a fair one. The question of the presence of water in ducts and manholes also is not fairly compared with what might happen here for the same reason, that they are operating with grounded systems, and practically selecting the ground as the other wire. In this test the return wire is in the line and no part of it would be grounded, and moreover, it is alternating current, and the results will naturally be very different.

L. L. Elden: I do not know whether or not the gas problem which is encountered in city practise is appreciated, but at any rate it has become necessary in Boston to ventilate the manholes, and I am at a loss to know how it would be possible to maintain air pressure with a 4-in. (10-cm.) opening in every manhole, beginning with the first one from the station. I believe such a system means a closed manhole system with many points provided for the supply of air, and provision must be made to avoid the collection of gas in pockets or dead-ended conduits. I believe this scheme was abandoned in New York for the reason that the conditions became prohibitive for its operation. Professor Puffer has spoken about water in conduit systems. There is no question that at times it is a convenience to have in some systems, providing suitable means are available to remove it quickly when necessary.

David Harrington: In regard to the matter of regulation of air pressure, I would recommend a system of air circulation which was regulated through an underground system. I would not expect to turn air loose in a system and let it take care of itself.

I think people do not appreciate how comparatively easy it is to ventilate and maintain a proper temperature through a very considerable length of conduit. Personally, I never have been a great believer in ventilated manhole covers as a method of ventilation for a system. There are two or three things about it which I think are bad. In the first place the system does not stay open because most of the holes get plugged up, and then if it does stay open, in my experience, it does not ventilate the manhole. But I would recommend an absolute system of ventilation through manholes and of cooling through manholes, and I believe it can be done without regard to the manhole covers. I would say this, however, that in order to make an efficacious system for ventilating and cooling the ducts, the ducts must be tight. That is the case with any method; whether you are going to cool by air or water or something else, you must have a tight duct.

L. L. Elden: Another word in regard to ventilating manhole covers. A simple test at the perforations in such covers readily shows that as a means for establishing a circulation of air within the conduits, this method of ventilation is reasonably efficient. In practise it has been noted that where double or otherwise tight manhole covers are employed, explosions are much more destructive than where perforated covers are used. In the first case, the street surface is usually severely affected, while in the latter only the cover is dislodged.

Philip Torchio: Mr. Mosman gives the results of heating of cables in ducts for a subway structure consisting of 81 ducts. Modern practise is against the adoption of a large number of ducts in one trench as has been found that it is not economical to practically halve the carrying capacity of the cables to save a few cents in conduit construction.

A very important subject brought up by Mr. Mosman is the effect of alternating currents on single-conductor leaded cables. The New York Edison Company has on several occasions carried out tests along the lines followed by Mr. Mosman, and I present herewith two reports, one of January, 1907, and one of April 1912, which may pertinently supplement Mr. Mosman's results as they were carried out for frequencies of 25 and 60 cycles, instead of the frequency of 40 cycles dealt with in the author's paper.

I think that all of this information is valuable to central station engineers, as information of this character is rather meager. As to some conclusions of Mr. Mosman, I am not prepared either to endorse them or to take issue with them. I want, however, to point out that there may be disadvantages in relying on the maintenance of insulation in ducts and manholes for a long single-conductor leaded cable carrying large alternating currents. A safer procedure would probably be the frequent bonding and grounding of the lead sheaths so as to reduce the amperes flowing in any one length to a moderate amount.

For low tension work, however, as for instance in the case described in the paper, I would consider the use of concentric or multi-conductor cables preferable to the single-conductor cables. Where single-conductor cables must be used some form of waterproof insulation and braiding could be used to advantage for voltages not exceeding 2000. For higher voltages braided cables must be, in addition, supported by highly insulating clamps to prevent their destruction from static discharges to neighboring high-resistance grounds.

Induced Currents in Cable Sheaths—January, 1907. The following tests were made to measure the currents induced in the lead sheaths of the cables on generator No. 10 in Waterside Station No. 2.

Length of cables.............	106 ft. (32.3 m.)
Outside diameter............	2⅜ in. (60.3 mm.)
Thickness of lead............	⅛ in. (3. 175 mm.)
Copper......................	1,500,000 cir. mils
Cross-section of lead.........	0.8835 sq. in. (5679.7 sq. mm.)
Resistance of lead............	0.000105 ohms per ft. (304.8 mm)

When tested, these cable sheaths were permanently bonded and grounded at the upper end in the transformer gallery. All other bonds and grounds were cleared, down to the generator terminals, where the bond wires were opened for measurements. Under these conditions the sheath circuits were star-connected, and it was found that the open-circuit voltage from end to end on one sheath was 1.38 volts, with 360 primary amperes. Reading across the open ends of two legs, 2.56 volts was observed, against a calculated voltage of 2.39, assuming the two to have a phase difference of 120 deg. ($\sqrt{3} \times 1.38$).

Upon completing the circuit by joining the generator end to a common connection through an ammeter, the voltage from end to end dropped to 1.10 volts, the current flowing along the sheath being 15 amperes.

With 632 amperes, a current of 44 amperes was measured, flowing from the sheath to the common connection.

A test for unbalanced current to ground was made by observing the current in the three leads from the sheaths to the common connection, and also the current flowing from the common connection to ground.

With 360 primary amperes, the currents flowing along the three sheaths were about 18 amperes, while the current to ground was 0.35 ampere. As the ammeters and connections were not all of the same resistance, this probably accounts for the unbalanced current.

A bond was made in the basement about 35 ft. (10.6 m.) from the generator and tying the three sheaths together, under these conditions the current at the generator end was reduced from 26 amperes without the bond, to 12 amperes with the bond, with 450 primary amperes.

In general, therefore, it appears that the currents induced in the sheaths are balanced, or nearly so, and that if the bonds between the sheaths are heavy enough, and make good contact, there will be practically no current to ground. In order to reduce the current flowing in any bond wire, several bonds should be provided.

For the No. 10 generator cables at Waterside Station No. 2, it appears that with 25 cycles, 800 primary amperes, bonds about every 40 ft. (12.2 m.) should not have more than about 18 amperes flowing in them. It would seem to be sufficient to ground the bonds at the ends of the cable, if the bond connections are all made with good contacts.

Induced Currents in Lead Cable Sheaths—April 30, 1912. The following tests were made to measure the currents induced in the lead sheath of a 1,500,000-cir. mil single-conductor cable. The tests were made in comparison with a similar cable with braid covering.

The two sample cables were drawn into tile ducts, both in outside ducts and separated from each other by an empty duct; this location placed them 14 in. (356 mm.) apart between centers. The two cables were connected together at one end, and current was passed through them in series. The two ends of the lead sheath were connected together through a 500,000-cir. mil cable. Complete measurements were made in the main circuit for both the lead and braid covered cables, and also in the sheath circuit. The ducts were broken away at a point about midway from the ends, in order that temperatures might be observed at this point.

The detailed dimensions of 'the samples were as follows:

Lead-covered cable: 1,500,000 cir. mil; conductor diameter 1.625 in. (41.3 mm.); sheath diameter, inner, 2.125 in. (54 mm.), outer 2.375 in.

(60.3 mm.); 190.1 ft. (57.94 m.) long. Braid-covered cable: 1,500,000, cir. mil; 191.5 ft. (58.37 m.) long.

Resistance at 23 deg. cent.

Conductor of lead-covered cable = 7.58×10^{-6} ohms per ft. (304.8mm.)
" " braid- " " = 7.43×10^{-6} " " "
Lead sheath = $117. \times 10^{-6}$ " " "

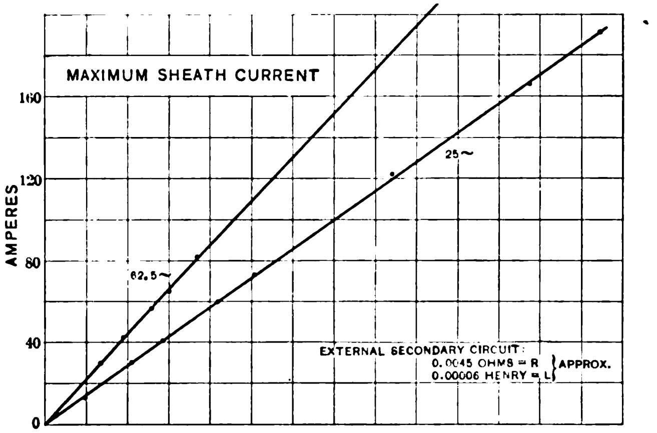


FIG. 1

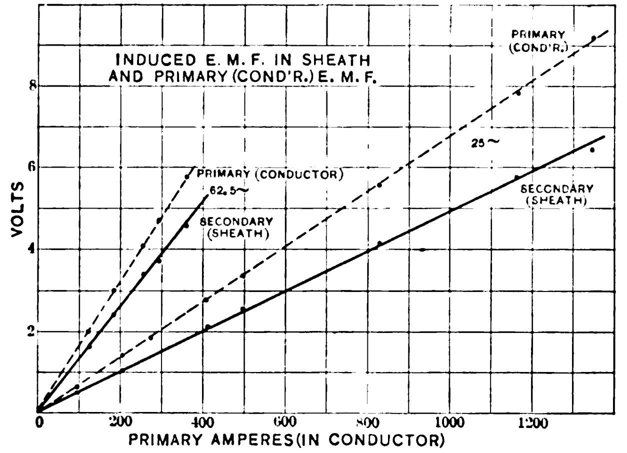


FIG. 2

Measurements were made of induced volts in the sheath, current flowing in the sheath circuit when connected through an external conductor, and losses, and the results are shown in the accompanying curves, Figs. 1 to 7. The currents measured are probably maximum currents, or as high as may be expected in practise, as the connections and external circuit were all of low resistance.

Fig. 2 shows the e.m.f. induced in the sheath, together with the impressed voltage on the conductor as primary volts. Fig. 1 shows the current flowing in the sheath and external circuit, when the ends of the sheath are joined.

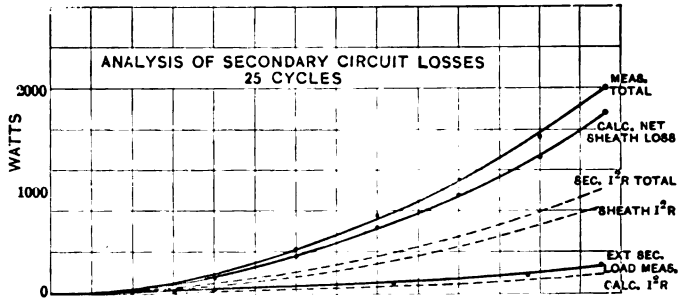


FIG. 3

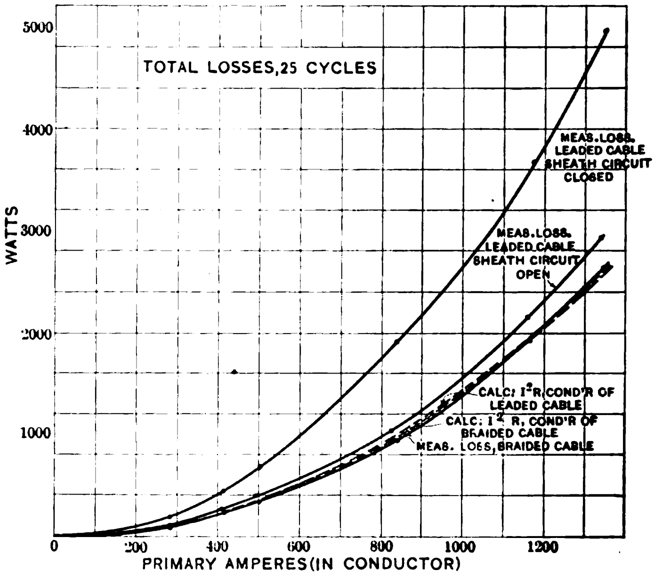


FIG. 4

Fig. 4 shows the measured and calculated losses in the leaded and braided cables at 25 cycles. Comparison with the calculated I^2R loss shows close agreement for the braid cable, within the accuracy of the measurements; the leaded cable, however, shows a materially greater loss than accounted for by calculated I^2R

with the sheath circuit open; this difference is apparently due to eddy currents in the sheath.

Fig. 3 is an analysis of the secondary circuit losses at 25 cycles, that is, both the losses in the sheath itself and the losses in the conductor connecting the ends of the sheath, considering the sheath as a transformer secondary and the connection as an external load upon this secondary. It will be seen that the measured power in the external load agrees fairly with the calculated I^2R, probably within the accuracy of the measurements; the net loss in the sheath, however, is nearly twice the calculated I^2R. It was not possible, with the available facilities, to further analyze this loss, and we are unable to state whether it is due to increased eddy currents, or not.

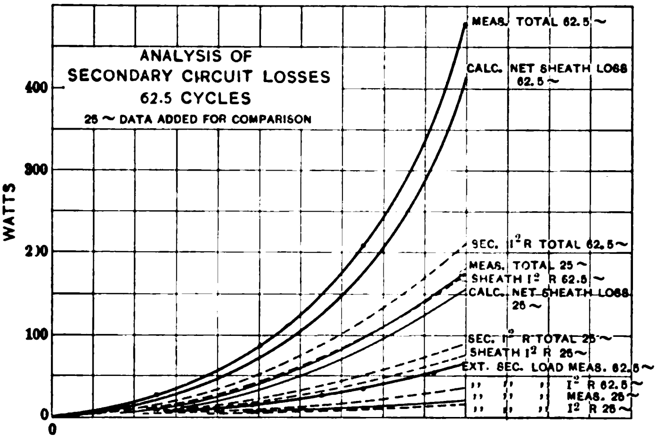


FIG. 5

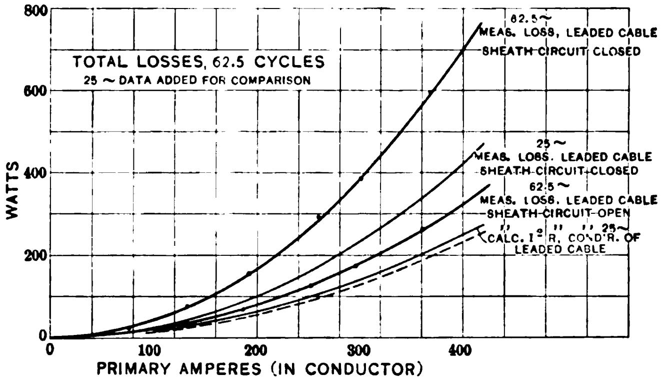


FIG. 6

Fig. 6 shows the measured and calculated losses in the leaded and braided cables at 62.5 cycles. As in the 25-cycle test, the loss in the braided cable is substantially the same as the I^2R, while the leaded cable shows an excess over I^2R, more marked than at 25 cycles, and probably due to eddy currents in the sheath. The 62.5 cycle test could only be carried up to about 400 amperes on account of limited supply. and for that reason some of the more important 25-cycle values are re-plotted in Fig. 6 and also in Fig. 5, for comparison.

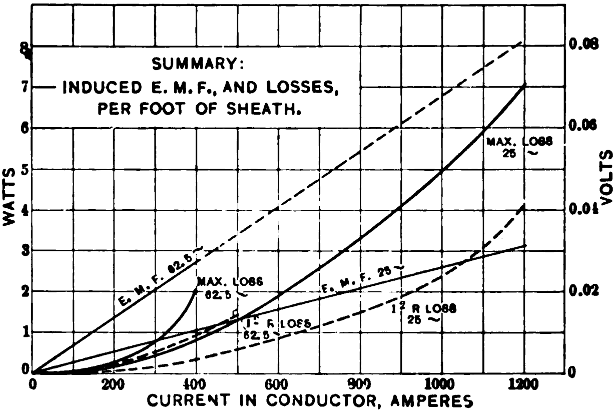


FIG. 7

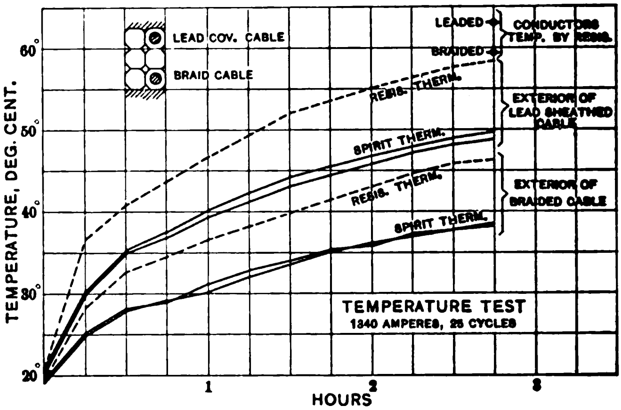


FIG. 8

Fig. 5 is similar to Fig. 3, and is an analysis of the secondary circuit losses at 62.5 cycles. The excess of measured loss over I^2R for the sheath is shown here, as in the 25 cycle test, the ratio being about the same, approximately two to one.

A summary of the foregoing tests is shown in Fig. 7, giving the induced e.m.f. and losses per foot of sheath, for primary currents up to 1200 amperes.

Temperature Tests. A temperature test was made by passing 1340 amperes, 25 cycles, through these two cables in series, and observing the temperature of the outside of the cables until practically constant temperature was reached. The temperature of the conductors was also obtained, by resistance, at the end of the run. Throughout the test, the sheath circuit was closed and a current of 192 amperes flowed in the sheath. The results are given in Fig. 8.

The resistance thermometers were in close contact with the outer surface of the cables, at the breaks in the duct described above. The spirit thermometers were thrust down inside of the ducts, as far as they could be read.

C. T. Mosman (by letter): The discussion has shown the possible need of emphasizing certain points in the paper in order that there may be no misunderstanding of the author's ideas of its range of application.

It is quite evident that the location, arrangement and loading of this duct system are such that to draw conclusions therefrom which will be applicable to the usual city installation would require considerable practical experience with underground systems and unusually good judgment. If it were necessary to carry 81 ducts under a city street and for any considerable distance, undoubtedly an attempt would be made to arrange these ducts in two or three separate sections, sufficiently separated so that there might be an appreciable spacing of earth between the adjacent sections, thus enlarging the exterior radiating surface of the system and consequently its contact with the surrounding soil. This arrangement would be much superior to the idea suggested by Professor Puffer, of having a central air duct or space, which would serve little purpose in carrying off heat unless a definite circulation of air were maintained, and even then it is doubtful if the arrangement would allow of as high carrying capacity per square foot of section as would be obtained by division of the ducts into separate sections.

Apparently Mr. Elden has misunderstood the temperature limitations for the various types of insulation given at the top of the second page of the paper. The temperatures there given are the total temperatures in deg. cent., not temperature rise, and hence are apparently still more at variance with Mr. Elden's ideas. The temperatures given by Mr. Elden are extremely interesting, but it should be noted that they are the temperature rises presumably in deg. cent. of the cable sheath at the manhole above the temperature of the air in the manhole. A reference to Figs. 12 and 15 indicates that there may be considerable difference between these terminal temperatures and the temperatures obtaining at some other point in the duct, Fig. 15 indicating a difference of 28 deg. It should also be borne in mind that some of the cables referred to by Mr. Elden are insulated for high potential, and hence that a very appreciable allowance must be made for the fall of temperature through the insulation, and thus it is safe to assume that if a temperature rise of 30 deg. is obtained at the manhole with the air temperature at 25, or a total temperature on the cable sheath of 55 deg. cent., the temperature of the copper at some point in the duct may be easily in the neighborhood of 100 deg. cent. Cables might operate at such a temperature for a considerable number of years before giving evidence of deterioration. At the same time it does not seem to the speaker that such operation should be considered good practise.

The bonding recommendations made in the paper are suggested as applicable only to the particular installation under consideration, or other very similar installations, and are by no means considered applicable to street service. It should be kept clearly in mind that the cables under consideration in this paper are single-conductor, lead covered, carrying fairly large currents and hence in no wise comparable with the triple-conductor cable, which would generally be used for carrying three-phase currents in a city system.

In the London *Electrician* of September 2, 1905, appeared an article by Mr. Morris showing that in a triple-conductor cable with insulation between wires of 0.35 in. (8.89 mm.) and a $\frac{1}{8}$-in. (3.175-mm.) lead sheath carrying 50 amperes at 60 cycles, the energy loss in the lead sheath was but 0.3 per cent. of the copper loss in the cable, thus indicating that for a triple-conductor cable in a tile or fibre conduit the sheath loss may be neglected. For the same cable in an iron pipe the sheath loss would be increased about 75 per cent. Fig. 23, Curve 2, in the author's paper indicates that with the single-conductor cable carrying 450 amperes, a sheath current of 75 amperes might be expected, this test being made at 40 cycles, the sheath current being in this case about 16 per cent of the current in the cable.

In the London *Electrician* of April 15, 1905, is an article by Mr. Field stating that in the case of two cables 12 in. (305 mm.) apart and carrying 200 amperes at 60 cycles, a sheath current of 64.5 amperes was obtained, the sheath current hence being 32 per cent of the current carried by the cable. If proper corrections are made for the difference in frequency and for the difference in the thickness of the lead sheath and the amount of current carried by the cable, I think it will be found that the sheath currents given in the paper are in reasonable agreement.

The limiting capacity of the cables in a duct system should be dependent upon the exterior perimeter of the total conduit section, again indicating the desirability of sectionalizing a large system. The 9 by 9 section under consideration operating at 2 watts per duct foot (1 ft. = 304.8 mm.) or 62 watts per conduit foot, has outside dimensions of approximately 4 by 4.5 ft. (1.2 by 1.37 m.), or a total perimeter of 17 ft. (5.18 m.). If the radiating surface of the top of the system is neglected, there results a perimeter of 13.5 ft. (4.115 m.) hence the radiation must be 12 watts per sq. ft. (0.0929 sq. m.) of radiating surface. From 6 to 12 sq. ft. of radiating surface, neglecting the area of the top, may be considered good practise in the case of manholes containing transformers or other devices giving off considerable heat; the proper limit, of course, depending greatly upon the condition of the surrounding soil, particularly with regard to dampness; hence on this basis the limit of 2.5 watts per duct foot would again appear reasonable.

Professor Puffer has suggested the flooding of the duct system with water in order to increase its capacity. This was one of the first ideas that occurred to us, but it was discarded as not practical. There is no doubt that by this means the capacity of the duct system might be enormously increased, particularly if the water were circulated. The risk of puncture of the cables due to small holes in the lead, the increase of sheath currents, the probability of the lead being subject to chemical action and electrolysis due to impurities contained in the water, and the inconvenience of emptying the system to make it possible to inspect or work upon the cables, and the fact that a portion of the duct system is above the basement floor of a building, are all strong arguments against such an arrangement.

The tests forming the basis of this paper were carried out by Mr. William Clark, who was sent to the plant with very broad instructions to obtain data in the best way available. The work was done in the winter and involved very serious discomfort, and many unexpected difficulties were encountered. The working up of the data required something like 100 curve sheets. Mr. Clark was assisted in the carrying on of the tests by Mr. George A. Burnham and Mr. S. C. Coye.

Mr. Clark has already covered Professor Puffer's inquiry with reference to the testing of the iron wire. It should be borne in mind that no duct contained both an iron wire and a lead cable, and it should also be borne in mind that the principal and most interesting data were obtained by the use of a test coil which could be placed in any desired position in a duct, in this case the iron wire simply serving to produce heat.

Ralph H. Rice (communicated after adjournment): In connection with Mr. Mosman's paper I would like to call attention to the current carrying capacity allowed by the Board of Supervising Engineers, Chicago Traction. It is shown in the following table:

	Rubber-insulated lead-covered	Paper-insulated lead-covered	Triple braided weatherproof
1,000,000-cir. mil cable amperes............	800	1,000	1250
500,000-cir. mil cable amperes...........	500	600	625
350,000-cir. mil cable amperes..........	375	425	325
4/0 cable amperes.......	—	—	325

It will be seen that this carrying capacity is much more liberal than that indicated on the next to the last page of Mr. Mosman's paper.

We have found no trouble as yet with any of our cables which can be traced to overheating. In explanation of this, two things might be pointed out:

First.—That the duct lines in which these cables are placed are situated in trenches in the ground and not in the basement of a building, as the cables under test.

Second.—Mr. Mosman has tested cables in a conduit section, 9 by 9 ducts. It is the practise of the railway companies in Chicago to restrict the conduit section to a much smaller number of ducts than this. The largest duct section ordinarily used when unprotected by concrete or earth walls is 12 ducts. When we have 16 ducts, or over, the section is broken by a 4-in. (10-cm.) vertical concrete wall, so that in any one compartment there are not more than 12 ducts.

R. W. Atkinson (communicated after adjournment): Mr. Mosman's paper is of very great value in showing limiting carrying capacity in such an unusually large duct system. The writer will confine his discussion largely to two subjects covered by the author. He expects to show that the heat conduction lengthwise along the copper and lead is far less important than seems to have been assumed by the author. We are presenting data from which may be calculated the current which will be induced in the lead sheath of single-conductor cables carrying alternating current. Also data are given showing the amount of voltage induced when the sheaths are insulated from each other so as to prevent the current flowing. The energy loss due to the sheath current is very important in many cases (as for instance that described by the author) but the dangers due to the induced voltages may be even much more serious.

In several places, the author explained some of the results obtained on the assumption " that considerable of the heat generated in the test wires must have been dissipated by the cables operating at low loads." (See pages 765 and 774.) Also on page 770, he says " the lead sheaths of these cables presumably conducted heat to the end of the ducts and dissipated it to the air in the manholes." The writer has made calculations showing that the influence of the lengthwise heat conduction is negligible as regards either the average temperature or the maximum temperature. We find in handbooks the heat conductivity of copper given as 0.72 g-cal. per deg. cent. per cm. cube. The conductivity of lead is approximately one-eighth as much. For copper, we may put these data in the form 2.01×10^6 thermal ohms (deg. per watt) per mil foot. That is, the heat resistance of 1 ft. (304.8 mm.) of 1,000,000-cir. mil cable is 2.01 thermal ohms, or a heat current of 1 watt will flow lengthwise when there is a difference of temperature between the ends of 2.01 deg. cent. From the dimensions of the cable given, we compute a cross-section area of the lead equal to 760,000 cir. mils. In heat conductivity, this is approximately equivalent to 95,000 cir. mils of copper. Mr. Mosman found the point of maximum temperature as near as 14 ft. (4.3 m.) from one of the manholes. We will make the following very rough assumptions, for an approximate calculation. From Fig. 5, test No. 1, 28 deg. cent. is considerably more than the difference in temperature between any test wire and the lead sheath of the cable at the mouth of the duct in the manhole. For convenience, we will take the resistance of the cable as two ohms per ft. (304.8 mm.) (on the assumption that both lead and copper are available for heat conduction, the resistance is about 10 per cent less than this). Assume that there is no heat conduction along this cable from a greater distance than 14 ft. (4.3 m.). Assume that over the 14 ft. a total of two watts is delivered from the test wire to the unloaded cable. Assume that an equal amount is contributed by each foot of the length, so that 2/14 of a watt is contributed by each foot length. The heat flow then in the cable at the duct's mouth will be two watts and one foot away wlll be decreased by 2/14 watt, and so on. Two watts heat flow will require a difference of temperature of 4 deg. per foot. The gradient will be gradually reduced until it reaches zero at 14 ft. Accordingly the total temperature difference will be 14 times the average gradient, or 28 deg. cent. Then if our assumptions are true, 2/14 watt of the two watts generated per foot in the test wire could be carried away by a single unloaded cable. This is only 1/14 or about seven per cent. of the total heat generated and would be expected to make about that per cent difference in the temperature. Even this amount is very small as compared to the difference expected to be accounted for in this manner. However, our assumptions have very greatly magnified this effect. It will be noted that the difference in temperature between the test wire and the cable is 28 deg. cent. at the duct mouth, and is 2/14 of a degree at the 14 ft. point. We have assumed that there is 2/14 watt flowing from the test wire to the cable at each point. It is very obvious that however good or however poor the intervening duct walls are as heat conductors, many times as much heat will be carried to the cable from the one-ft. portion near the duct's mouth as is carried to it from the one-ft. portion near the 14-ft. mark. More careful calculation along the lines suggested (preferably by the use of calculus) shows that the maximum temperature can be affected by but a small fraction of one per cent. On the assumption that the heat conductivity between the test wire and the cable is very high, about 4.5 watts might be dissipated instead of 2, at each end of the cable. This is slightly over three per cent of the 280 watts dissipated by the test wire, and indicates a *possible maximum* effect upon the average temperature. A calculation similar to the above would have convinced Mr. Mosman that he need fear no errors in his results due to this effect.

The writer has given some attention to the subject of induced current and voltage in armored and lead-covered cables. In a paper by H. W. Fisher* a method of calculation is given, which was developed by the writer. These data are now presented in more concrete form. Referring to Figs. 9 and 10, it will be seen that the voltage induced depends upon the frequency, the distance apart of the cables, and the diameter of the lead sheath. The voltage induced for either 25 or 60 cycles may be read directly from the curves. These data are shown much more readily, as we have done, on logarithmic paper. The current which is induced when the lead circuit is completed is shown for several sizes of lead sheath at both frequencies. Intermediate values may be interpolated fairly closely or may be calculated by the method below.

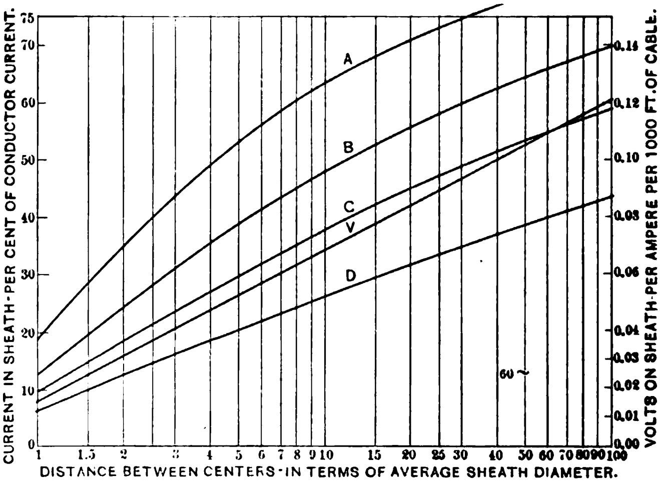


Fig. 9

The curves *V* in Figs. 9 and 10 give either reactance against neutral per 1000 ft. (304.8 m.) of cable, or voltage induced per ampere in the conductor at 60 cycles and at 25 cycles. The formulas for calculating this reactance are

$$X = 0.05295 \log 2 \frac{D}{d}\text{, for 60 cycles}$$

$$X = 0.02207 \log 2 \frac{D}{d}\text{, for 25 cycles}$$

The voltage induced $= IX$, where I is the current in the conductor.

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*Transactions A. I. E. E., 1909, XXVIII, II, p. 759.

The current induced in the sheath when the circuit is closed equals $\frac{X}{\sqrt{R^2 + X^2}}$ where R is the resistance per 1000 ft. of the lead pipe. (The resistance at 100 deg. fahr. (38 deg. cent.)

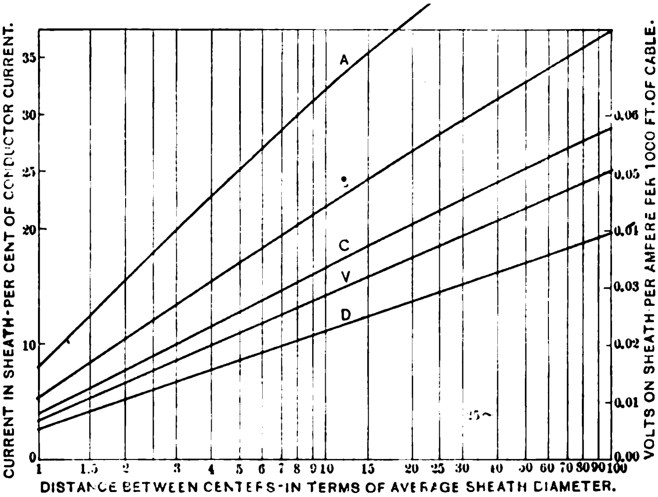


Fig. 10

Figs. 9 and 10.

Induced Voltages and Currents in Lead Sheaths.

Curve " V " gives the volts to ground on the lead sheath per 1000 ft. per ampere flowing in the conductor. For three-phase circuits the voltage between sheaths equals 1.73 times the value on the curve, or twice this value for single- or two-phase circuits.

Curves *A*, *B*, *C* and *D* represent the current induced in the lead sheaths when they are connected at the ends. 1/8 in. (3.175 mm.) thickness of lead has been assumed. Current is given in per cent of conductor current

Curve *A* for 3 in. (76.2 mm.) mean diameter of sheath
" *B* " 2 " (50.8 ") " " " "
" *C* " 1.5 " (38.1 ") " " " "
" *D* " 1 " (25.4 ") " " " "

If thickness of sheath is other than 1/8 in., use a diameter for calculation which with 1/8 in. thickness will have the same cross-section of lead as has the sheath under consideration. Where the sheath is less than 1 in. in diameter, the current flowing may be taken as approximately proportional to the cross section of lead.

***Power Lost.*—If *P* equals per cent of sheath current in terms of conductor current, add to the conductor resistance $(P/100)^2\ 0.25/d$, *d* being average sheath diameter. 0.25 is the resistance per 1000 ft. of 1-in. pipe (average diam.), 1/8 in. in thickness. If the thickness is other than 1/8 in., the energy lost is of course inversely proportional to the thickness for a given current.**

of a lead pipe having an average diameter of one in. (25.4 mm.) and a thickness of lead of $\frac{1}{8}$ in. (3.175 mm.) is $\frac{1}{4}$ ohm per 1000 ft.) Average diameter refers to the average of the internal and external diameters.

Example.—We take the following data from the paper of the author—Outside diameter of cable 1.65 in.; thickness of lead 0.125 in.; average diameter of lead 1.52 in.; resistance of lead sheath 0.182 ohms per 1000 ft.; distance between centers of cable (probably) 4 to 5 in.; frequency 40 cycles. We have, then, $\frac{D}{d}$ is 2.63 to 3.28. From curve *V*, Fig. 10 of this discussion we find that the reactance at 25 cycles is therefore from 0.019 to 0.0212 ohms per 1000 ft.; the reactance at 40 cycles is then about $0.020 \times \frac{40}{25} = 0.032$. The current in the lead sheath is then $\frac{0.032}{\sqrt{0.182^2 + 0.032^2}} I = 0.173\, I$, that is, 17.3 per cent of the current in the conductor. Mr. Mosman gives for the cables in the ducts under these conditions, 16.5% (test No. 2, Fig. 23.).

Mr. Mosman finds in another test, 33 per cent as much current in the sheath as in the conductor, after making allowance for resistance of bonds. He has made the correction as though for direct current. This is approximately correct, as the reactance is relatively small even in this case. Hence, there will be no error introduced if we assume the reactance voltage to be in proportion to the current produced, that is, that there is approximately 1.9 times the voltage in this case as in the former case. At 25 cycles, this would be 0.020 × 0.19, or 0.038 ohms per 1000 ft. From the same curve, we find that this reactance is obtained when $\frac{D}{d}$ is approximately 26. The separation between the centers of the cable in this test must have been approximately 1.52 in. × 26 = 40 in. (102 cm.). We have worked backwards purposely in this case, as the separation is not given in the report of this test, and cannot be deduced from the probable dimensions of the system as in the other case. We would not expect a close agreement, but one only roughly approximate, between this calculated value and the distance actually obtained in the test, since a very small difference in the value of the induced current found would make a very large change in this calculated value. Conversely, when it is desired to know the current which will flow, it is unnecessary to know accurately the distance between centers, as a considerable change in distance can be made with comparatively slight effect upon current produced.

We have presented the data with two-fold purpose, first, to make available a ready method of pre-determining conditions which will exist. The second reason is because we consider the unqualified recommendation to insulate the sheath of single-conductor alternating-current cables in order to prevent sheath current, an exceedingly dangerous one. Moreover, we believe that the lead sheath should be solidly grounded at some point instead of through a resistance. Otherwise, unless the station is of very limited output, an accidental ground on any of the cables means full station voltage impressed upon the entire sheath of the cable in question. Under the specific conditions mentioned in the paper, this would mean full station voltage upon all cables of one phase. Under these conditions, it is very improbable that the first ground produced would be the only one upon the system. It would be quite possible for arcs at different points to melt holes in the sheath and burn through the insulation to the conductors.

When sheaths are insulated the normal voltage to ground will be something of no mean value; as calculated above, the reactance per 1000 ft. (304.8 m.) is 0.032 ohms. With 500 amperes flowing in the conductor, this means a voltage to ground of 16 per 1000 ft. The voltage between cables of the opposite phase would be about 30 volts. If this were the maximum value encountered, it might not be serious and might cause no damage, if the means of insulation described by Mr. Mosman were in use.

However, we may have excessive sheath voltages induced if a short circuit occurs in the substation at the end of a cable without any failure whatever on the part of the cable itself. If the voltage is maintained at the power house during a short circuit, during the maintenance of the short circuit, there will be induced in the cable sheath a difference of potential nearly equal to the power house voltage. For example—the reactance at 40 cycles of a circuit consisting of two 1,000,000-cir. mil cables 1000 ft. long at 4-in. (102-mm.) centers is 0.067 ohms at 40 cycles. The reactance is 0.02 ohms, and resulting impedance 0.07 ohms. If the station voltage is 1000 volts and is maintained, more than 14,000 amperes will flow in short circuit. The reactance of lead sheath will be, for the 2000 ft. (609.6 m.), approximately 0.06 ohms. This multiplied by the short circuit current gives more than 850 volts. The damage which might be occasioned by the presence of such a voltage can still better be imagined when it is noted that the current which can flow if the opportunity is given, is a very considerable percentage of the short-circuit current flowing in the cable, in this case about 2500 amperes. It may be taken as a general rule, that, regardless of other conditions, where the lead sheaths are insulated from each other when a short circuit occurs at the end of the cable, a very considerable percentage of the cable voltage will be induced between the lead sheaths. This is both dangerous to the cables themselves and to the life of anyone approaching the supposedly grounded lead sheath.

DISCUSSION ON "POWER REQUIREMENTS OF ROLLING MILLS" (SYKES), AND "THE ECONOMICAL SPEED CONTROL OF ALTERNATING-CURRENT MOTORS DRIVING ROLLING MILLS" (MEYER AND SYKES), NEW YORK, NOVEMBER 8, 1912. (SEE PROCEEDINGS FOR NOVEMBER AND DECEMBER, 1912.) (CONTINUED FROM JANUARY, 1913, PROCEEDINGS, PAGE 84.)

(Subject to final revision for the Transactions.)

A. Dyckerhoff (communicated after adjournment): In going over the paper on *The Economical Speed Control of Alternating-Current Motors Driving Rolling Mills*, it occurs to me that some statements made in this paper are misleading, and also that many points are not brought out which should be mentioned. While I do not wish to invade the territory of the rolling mill engineer, whose task it is to find out the best rolling methods, and to whose needs the electrical manufacturer has to adapt his machinery in ways consistent with the best engineering practise, I wish to make a few remarks as an electrical engineer connected with steel and rolling mills. I feel myself the more qualified to speak since I had a very good opportunity during the past summer to study in Germany the question of economical speed regulation of a-c. motors, and its reliability in practical application under severe conditions.

The objection may be made that the rolling mill practise in this country is more severe than in Europe, and requires also, on account of the more or less unskilled labor, machinery of the most heavy construction and with practically fool-proof control. It will be seen, however, from the following statements, that all such objections to the adaptation of similar devices can be easily overcome. These devices are selected for their value in giving more definite speed control as a refinement in the art of rolling steel, and for cheapening the cost of producing rolled steel through more efficient operation.

The statement is made that speed regulation on merchant mills depends greatly on the class of labor operating the mill. Naturally a certain gang will have to be trained for a particular mill or class of work, but the lack of skilled labor should not impose the necessity of providing arrangements for speed regulation which would otherwise be unnecessary. In the case of merchant mills of the continuous type for high production the rolling process is almost automatic, and when steel is being rolled at very high speed, *e.g.*, in three-high rod mills, unskilled manual labor can be almost entirely dispensed with by using "guides" leading the metal from one pass to another.

It is the nature of the rolling process that merchant mills with a wide range of work require speed adjustment, particularly mills rolling refined material such as tool steel, spring steel, etc., where accuracy of section is necessary. This applies especially to mills running at low speed and rolling higher grade sheet and tin plate, stampings for electric machinery, etc. In most of these cases speed adjustment is essential for reasons of quality of metal and finish of product. Metal of this kind is often worked at low temperatures, thus requiring more power. Since many firms rolling such material do not own electric power plants, but have to buy electric power, they are particularly concerned with putting in the most economical speed adjustment devices they can get.

There are certain other applications where speed regulating devices are desirable in order to secure better operating conditions. Continous mills, a type much in evidence in this country may offer possibilities for great improvement in conditions, due to their large output. Where the range of product of an existing mill is increased by adding several roll stands, a small regulating set attached to the roll motor may increase its output sufficiently to carry the entire load under the new conditions, whereas a larger motor would be otherwise required.

Rheostatic Control. It is pointed out above that in many cases a steady speed regulation is required, for rolling reasons. It follows that a resistance control cannot, for inherent reasons, give as good results as can be obtained by the new speed regulation devices, even if an automatic regulation of the resistance is applied so as to vary it inversely with the load. In ordinary merchant mills a speed regulation of from 10 to 15 per cent of synchronous speed, obtained by rheostatic control, may be just as economical under certain conditions as that obtained by regulating sets, and being more practicable is therefore more desirable. That a rheostatic speed regulation of 25 to 30 per cent can be just as economical as that obtained with any other auxiliary arrangement, not considering the question of satisfactory operation, is an assertion that will not hold true in ordinary practise. In the example cited of a jobbing mill carrying full load only 20 per cent of the running time, a condition is illustrated that is rarely met with, as it means bad mill practise and excessive costs due to light running. Furthermore, several points are omitted which should be taken into account. First of all, the power factor on the motor decreases with the rheostatic regulation considerably; further, the efficiency of the converting equipment, including transformer, is rather low (about two per cent higher could be obtained at full load and three per cent higher at light load with a proper arrangement). I assume that the transformer mentioned was connected between the rotor ring and the converter, but the transformer, however, can be entirely dispensed with, since it does not assist in the cheapening and improving of the arrangement in any way. There is also an improvement of the power factor on the motor to approximately 100 per cent over almost the entire range of regulation, which means that a motor of a smaller rating could eventually be chosen. Any of these points should be fully taken into account; however, none has been mentioned. It is nothing but fair to consider the efficiencies of the different regulating sets and rheostatic regulation under equal conditions as found in ordinary practise, and to leave out entirely exceptions due to certain local conditions. This assumption of general conditions is illustrated by the curves in Fig. 4 of this discussion, which are based on actual tests representing present-day practise. It will be noted that the best result has been obtained by the converter d-c. motor system, and therefore the statement remains to be proved that some of the newer methods, referred to on page 2182 of the paper by Messrs. Meyer and Sykes, give more economical regulation than an arrangement requiring the conversion of the energy to direct current.

Multi-Speed Motors and Motors in Cascade. It is a matter of fact that the control of those motors is rather complicated. When dealing with a motor arranged for pole changing, this arrangement provides for a few speed steps only, the intermediate steps being obtained by inserting resistance. The power factor of such a motor is poor, consequently the generators and lines are loaded unnecessarily with current. In the case of two motors in cascade this feature of a low power factor is still more doubtful, the cascade motor forming a high inductive resistance for the main motor, thus resulting in high wattless current in the system. If there is a choice between a multi-speed motor and motors in cascade, the former is preferable. The latter arrangement is used in very few installations in this country as well as in Europe, where they have been using d-c. roll motors which are so ideal as to speed regulation, to a greater extent than in this country.

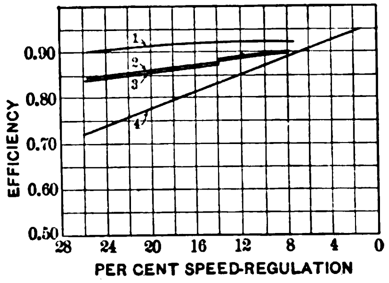


Fig. 4—Efficiencies of Various Regulating Systems in Relation to Speed Regulation

(1) Synchronous converter—d-c. motor system (Kramer). Main motor—1150 h.p., 270 rev. per min.
(2) Frequency changer system (Heyland,) Motor—950 h. p., 300 rev. per min.
(3) Scherbius system. Main motor—1000 h. p., 363 rev. per min.
(4) Rheostatic control. Motor—1200 h. p., 248 rev. per min.

Regulating Sets. There are four different kinds of regulating systems in successful operation:

1. Induction motor with synchronous converter, feeding d-c. motor, connected mechanically to shaft of induction motor, known as the Krämer set.
2. Induction motor with three-phase commutator motor coupled to same.
3. Induction motor connected electrically to three-phase commutator motor which drives induction machine feeding back to the line, known as the Scherbius set.
4. Induction motor with frequency changer feeding its secondary energy back to the line, known as the Heyland system.

Application. The nature of rolling processes generally requires high torque and low speed for heavy stock, and low torque and high speed for light sections, and also, when rolling a certain section, high torque at low speed is necessary for the first passes and light torque and high speed for the last passes. The rolling mill is therefore entirely a constant output proposition, *i.e.*, the torque increases with decreasing speed, whereas in the case of fans, blowers, and pumps, low torque is wanted at low speed. From this it follows that the d-c. motor system (set No. 1) and the three-phase commutator motor cascade (set No. 2) are in their nature more adaptable for roll trains than any other system, of which the two latter is more preferable on account of requiring only one additional machine and converting the secondary energy of the induction motor directly into mechanical power. I know of installations where such sets, arranged for a regulation of more than 30 per cent on merchant mills, are operating very satisfactorily. This country is more fortunate than Europe in using 25-cycle circuits for steel mills, which makes the design of three-phase commutator motors easier, although the output is limited. The maximum speed regulation in operation with the Krämer system is somewhat more than 60 per cent in connection with an induction motor of 1000 h.p. There is under construction a set calling for the regulation of a 2000-h.p. motor over a range of 55 per cent. The two systems, Krämer and d-c. commutator motor cascade, thus respond, to a great extent, to the needs of rolling practise, but this does not do away with the great usefulness and adaptability of the other systems. Some of the merits of the remaining systems are as follows: (1) they are very suitable for a high range of regulation; (2) they can be designed for their most suitable speed; (3) they can be placed independently of the mill itself; (4) they possess certain other advantages mentioned in the course of the discussion. Thus far a Scherbius set is operating in connection with a roll motor of 1800 h.p. with a speed regulation of 50 per cent, and a Heyland frequency changer in connection with a 900-h.p. motor for approximately 45 per cent regulation. If a choice is to be made between the three-phase commutator motor cascade and the Krämer set, the former is preferable for a roll motor running at high speed for a limited range of speed regulation, and for motors at medium speed and speed regulation usually met with, say, up to 65 per cent, the Krämer set is preferable; and for slow-speed motors with wide range separate regulating sets should be chosen. Thus far the Krämer set seems very adaptable for this country, as the design of the synchronous converter has reached a higher stage of development in the United States than in Europe, its reliability is proved by its extended use in power stations and railroad service, and its operation is familiar to attendants. Also, the three-phase commutator motor cascade promises from its successful operation as single-phase motor in railroad service, to be a reliable asset in steel mill drives.

Number in Operation. It is interesting to note that approximately 57 motors with a total rating of approximately 64,000 h.p. (continuous rating at high speed of main motor only) are equipped with economical speed regulating devices, of systems 1, 2, 3, or 4. Of this 64,000 h.p. motors totalling approximately 17,000 h.p. are under construction or are intended for speed regulation. The total amount of 64,000 h.p. is distributed among the different systems approximately as follows:

Synchronous converter-d-c. motor system	57 per cent.
Scherbius system	19 per cent.
Three-phase commutator motor cascade	18 per cent.
Frequency changer system	6 per cent.

Of this 64,000 h.p. approximately 12,000 h.p. is driving fans, blowers and pumps, and 45,000 h.p. is driving roll trains, the distribution of which on the various systems amounts approximately to:

Synchronous converter-d-c. motor system	75 per cent.
Scherbius system	13 per cent.
Three-phase commutator motor cascade	9 per cent.
Frequency changer system	3 per cent.

From these statistics it will be seen to what a great extent (about 70 per cent) the roll train motors share in the total amount, and to what a great percentage (75 per cent) the synchronous converter-d-c. motor system is represented. The latter system is also supplied for a great amount of the 17,000 h.p. under construction. The frequency changer system was brought out only about two years ago, which accounts for its small share.

Efficiency. Besides having a reliable operation it is of the greatest interest to learn what efficiencies have been obtained in actual service. Fig. 4 (see *Electrische Kraftbetriebe und Bahnen*, 1912, No. 21) shows the overall efficiencies of three systems with their respective motors compared with rheostatic control. These motors are driving fans, are approximately of the same output, and therefore permit the direct comparison as shown. From this it will be seen that the synchronous converter-d-c. system gives the best efficiencies, followed by the frequency changer system and the Scherbius system, which operate practically at the same efficiency. I understand that the efficiencies of the latter two have been increased lately.

Further, the curves show that the efficiencies of the Krämer set and rheostatic control are approximately the same at 4.5 per cent speed regulation, and those of the frequency changer and Scherbius system and rheostatic control the same at approximately 7 per cent. This means that a speed regulation above 4.5 per cent and 7 per cent, respectively, in these particular cases, is therefore more economical with regulating sets than with rheostatic control. The synchronous converter requires approximately at least two cycles for operation free from hunting, which means that with a frequency of 25 cycles, as used in steel mills, operation for less than about 8 per cent speed regulation will not be very satisfactory.

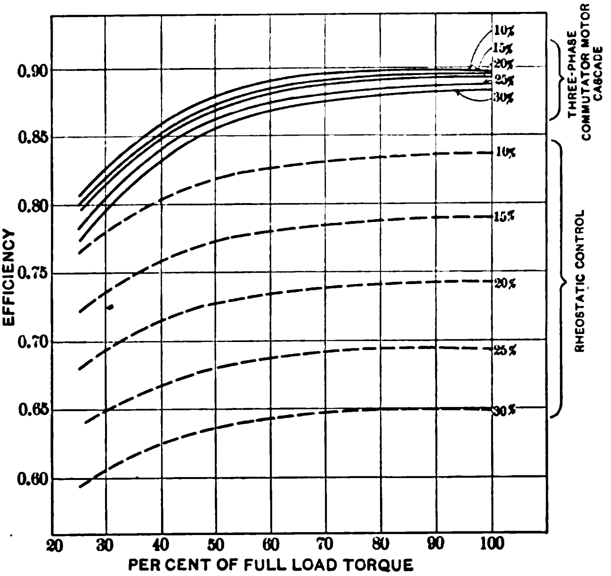


FIG. 5—EFFICIENCY CURVES FOR SPEED REGULATION BY MEANS OF THREE-PHASE COMMUTATOR MOTOR ON ROLL MOTOR SHAFT COMPARED WITH RHEOSTATIC CONTROL. MAIN MOTOR 1000 H.P., 360 REV. PER MIN.

Fig. 4 does not give the efficiency of a three-phase commutator motor cascade set; this, however, can be taken from Fig. 5 (See *Electrische Kraftbetriebe und Bahnen*, 1910, Nos. 6 and 7), showing efficiencies of such a cascade set compared with rheostatic control. It will be noted that such a set has an efficiency of approximately two to three per cent less than the synchronous converter-d-c. motor system.

For comparison of a three-phase commutator motor cascade set with a Scherbius set Fig. 6 (see *Electrische Kraftbetriebe und*

Bahnen; 1910) has been prepared, and it will readily be seen that the three-phase commutator motor cascade is superior in efficiency to a Scherbius set by several per cent, depending on the amount of regulation and on the torque. The efficiency of the Scherbius set is better than if there is a roll motor and a three-phase commutator motor operating at a very low speed. How far the efficiency is affected by a speed drop of 5 per cent from no load to full load, so as to obtain energy from the fly-wheel, is shown by the dotted lines. This disadvantage of a lower efficiency of the Scherbius set, however, is rather compensated by other advantages. In connection therewith, I would mention that by means of such a set 18 to 20 per cent of the energy taken by a roll motor of 1800 h.p. at 375 rev. per min. driving a rod mill was actually returned to the line, this being the average over several months and measured by actual readings of integrating wattmeters.

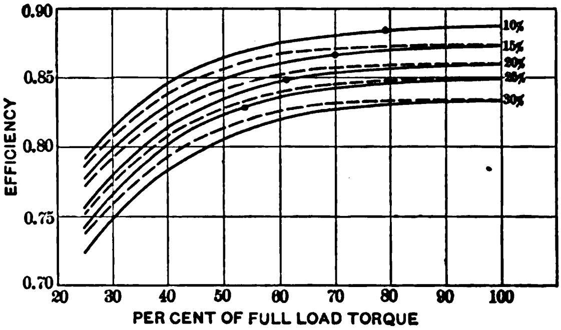


Fig. 6—Efficiency Curves for Speed Regulation by means of Scherbius Set, with and without 5 per cent Speed Drop from No Load to Full Load for 10, 15, 20 and 25 per cent of Normal Speed. Main Motor—1000 h. p., 360 rev. per min.

Power Factor. With any of the regulating sets mentioned, the power factor of the circuit has been brought to unity and the sets operate usually under this condition. A high power factor is the more important since the output of an existing motor can be increased, or in a new plant a main motor of smaller output can be chosen under proper conditions by adding a regulating set or a three-phase commutator machine as a phase compensator. Fig. 7 shows that unity power factor has been obtained with the synchronous converter-d-c. motor, the Scherbius and the Heyland frequency changer systems. The same result can also be obtained with a three-phase commutator motor cascade, but not, however, with such a simple device as with a Krämer set, where merely the excitation of the synchronous converter is regulated till unity power factor is obtained on the motor. The same effect can very easily be secured with a frequency changer; first, either by shifting the stator of the motor driving the frequency changer or, second, by means of double induction regulators if the frequency changer is connected to the main motor by means of a gear. Both of these methods are in successful operation. The disadvantage of the rheostatic control as compared with regulating sets is borne out by curve 4 of Fig. 7 of this discussion.

Control. A word may be said as to control, which is of such importance for successful operation. In most cases it is required to arrange the control so that it is fool-proof. Comparing the control for any regulating system with, for instance, that of a multi-speed roll motor, it will readily be seen that one is practically no more complex than the other. The sequence of switching operations in connection with regulating sets is very simple, and in all instances mechanical or electrical interlocks can be provided. Under certain conditions, *e.g.*, with a frequency changer, synchronizing is necessary, and this can be done by automatic synchronizers.

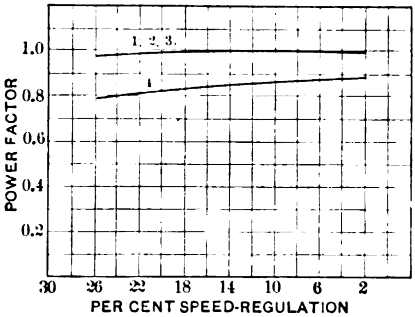


FIG. 7—POWER FACTOR OF VARIOUS REGULATING SYSTEMS IN RELATION TO SPEED REGULATION

In a great many installations phase-potential regulators have been used successfully, although this arrangement involves higher cost. The potential regulator has also been used in conjunction with the synchronous converter-d-c. motor system, connected between the rotor of the main motor and the converter, but not to the advantage of the regulating system, because of such drawbacks as additional high cost, large converter, lower efficiency, etc.

There is another important field of application of the three-phase commutator motor in connection with an induction motor and flywheel. This application is the more important in this country as the three-phase induction motor is being much used in connection with roll trains, whereas in Europe, due to other conditions, a great number of reversing mills are in operation which require a flywheel motor-generator set interposed between the line and the roll motor. This arrangement involves a triple conversion of energy from the switchboard in the motor room to the roll necks, and accordingly heavy losses. The tendency in this country is mostly to use the electric energy directly in the roll motors, thus requiring from the switchboard to the roll necks only one conversion of energy and saving the losses imposed by two more conversions.

It may be desirable to smooth out the peaks on the line where a motor drives the roll train directly, and in such cases a flywheel set with induction motor and three-phase commutator motor can give very good service. It is mainly the task of the three-phase commutator motor to enable the three-phase induction motor to act as a generator below synchronous speed, taking its energy from the flywheel and supplying current to the line. At the same time, the three-phase commutator motor takes care of the economical speed regulation of the induction motor. The whole arrangement can be made automatic.

A similar application of a three-phase commutator motor may also be useful in connection with an Ilgner set for the purpose of improving its efficiency.

The above points rectify some erroneous statements made in the paper and outline what really has been obtained under actual operating conditions in Europe, which same conditions hold true to a great extent in this country.

In regard to the systems described on page 2192 and following I would say that the above statements of a general nature which I have made hold true also for the new regulating arrangements, especially as to the adaptation of frequency changers to roll trains. These systems apparently represent some simple features, but so far are not yet proven by practical application, as far as I know, and the results will be awaited with interest. If there are any such installations I should like to know where they are located, also the output of the motor and the amount of regulation. I would further like to know for what theoretical reasons synchronizing of the frequency changers is not necessary, although I can anticipate the means for synchronizing which might be applied.

The main part of the switching arrangement of the frequency changer, as shown in Fig. 9 and Fig. 10 of the paper, and also of the three-phase commutator motor, Fig. 11 and Fig. 12, will consist of the control of the stator winding. These windings will have to have many taps in order to obtain a sufficient number of steps and thereby fine speed regulation. Furthermore, resistance steps or similar arrangements will have to be provided in order to avoid short-circuiting of part of the winding when switching from one tap to another. In connection therewith, I wish to say that the operation of three-phase commutator motors arranged for control by means of brush shifting has proved very satisfactory, and I learn that in consequence of this many are under construction.

Ford W. Harris (communicated after adjournment): It seems to me that the authors have made a little too much of a bugbear of the complexity of control and of control wiring. The latter may be eliminated at once as a matter of first cost only. That is, the control wiring can be so installed that it is absolutely no trouble to maintain. This is reasonable enough, as it is simply stationary material that may be protected against external injury. The multiplicity of switches is another matter, but even here a good word may be said for the simpler motors that may be used if a little switch complexity is allowed.

Further, it will be found that, by a little care in laying out the sequence of switching operations, that all the maintenance will fall on one or two switches and the remainder will be more or less free from arcing and wear. As to making them operate automatically, the writer has become convinced that there is really no question that, by suitable arrangements of interlocks and contacts, automatic control can be made practically infallible. The only requirement is good switches in the first place and a moderate amount of attention. It is my opinion that either a cascade or rheostatic control would probably work out more cheaply and be more satisfactory to maintain than either of the several commutator type systems shown. The item of economy is, of course, getting to be of importance, as the steel mill engineers are fast getting to a point where they can get absolutely satisfactory service and they are more and more bending their energies to the refinements that tend toward lower fixed charges and lower operating expense.

DISCUSSION ON "INDUSTRIAL LIGHTING" (ESHLEMAN), CLEVELAND, OHIO, OCTOBER 23, 1911. (SEE PROCEEDINGS FOR JANUARY, 1913.)

(Subject to final revision for the Transactions.)

F. T. Leilich (by letter): Mr. Eshleman has brought out in his paper a number of points that but few superintendents and managers of industrial plants realize. This lack of appreciation of proper lighting is a noticeable feature of many of the cotton mills of the South.

The conditions in these establishments are such that the lighting should be given special attention. The hours of working average from 6:15 a.m. to 6:00 p.m., with half a day on Saturday. Further, time lost in shut-downs, and these are not unknown, is made up at night. For a high-grade output and uniform quality, first-class lighting should be provided. A large percentage of these plants are engine-driven, requiring a maze of belting and shafting which obstructs the light. In mills of this class the generating equipment usually consists of a belted generator driven from the line shaft.

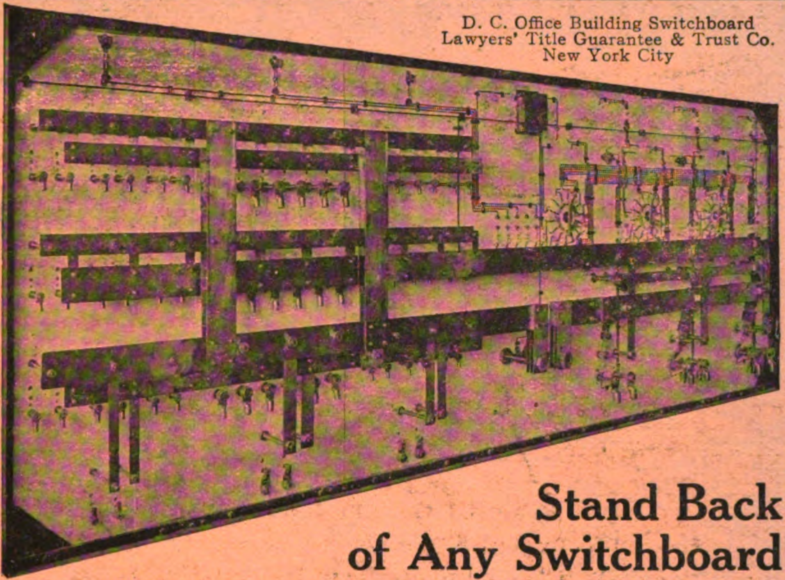
The lighting units are usually 16-c.p. carbon lamps either without shades or with flat enameled reflectors. The "smashing point" of a lamp is an unheard of thing and consequently lamps are burned long after they should be replaced.

In a recent examination of the power equipment of a cotton mill in South Carolina, it was found that the engines and boilers were loaded to the limit. Further investigation showed that carbon lights were used. In view of the fact that the management did not care to spend any money on new power equipment, it was necessary to relieve the boilers and engines in every possible way. Calculation showed a reduction of 3.5 per cent in maximum power required by replacing the carbon lamps with tungstens, and a corresponding relief to the boilers.

Conservative figures showed the yearly cost of tungsten lighting with 25-watt lamps to be practically the same as with 16-c.p. carbon lamps. The 25-watt tungstens being rated at 20 c.p., a gain in light flux of 25 per cent is obtained without any increased cost.

Further, a considerable increase in output resulting from a higher efficiency of the employee is possible with the tungsten system if properly laid out and equipped with suitable reflectors.

The yearly output of the cotton mills of North and South Carolina and Georgia for 1911 was valued at approximately $151,500,000. If say 50 per cent of the mills are in need of improved lighting and this increases the output by 5 per cent, the increase in value of the yearly products will be $3,787,000; certainly a good return on the investment.



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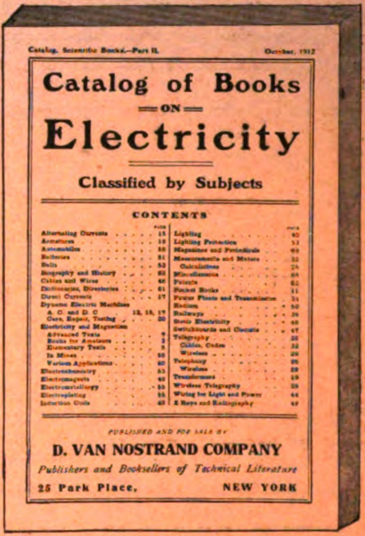

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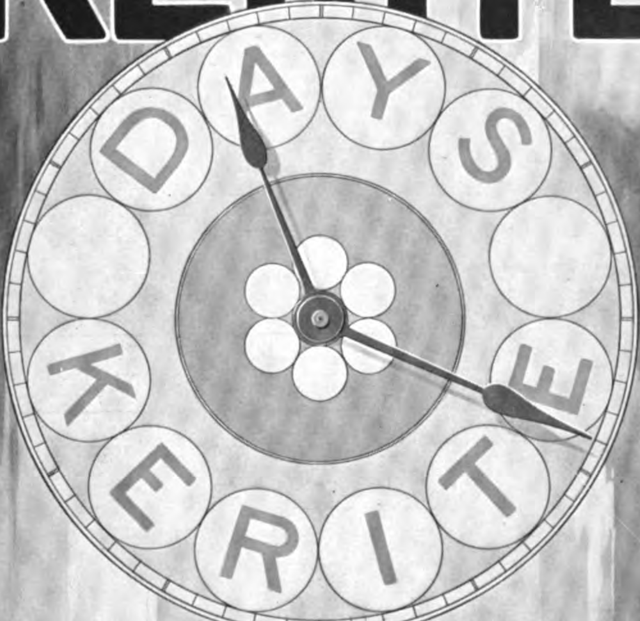

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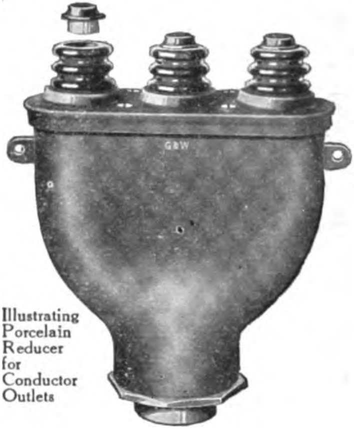

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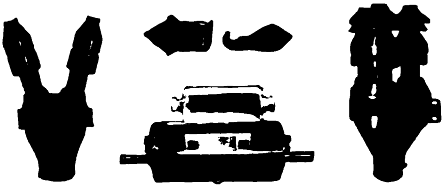

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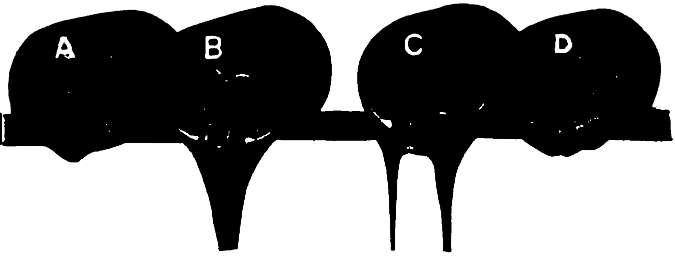

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(Continued from page IX)

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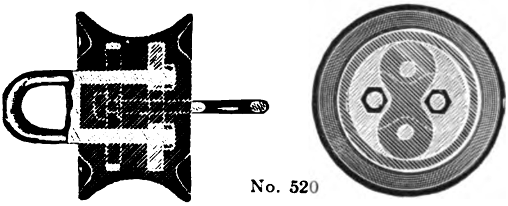

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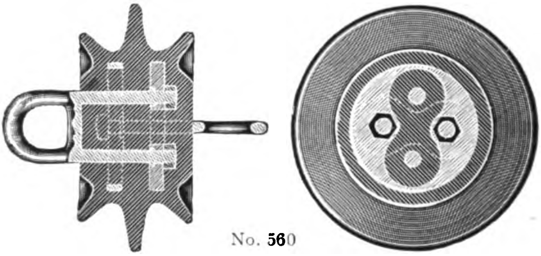

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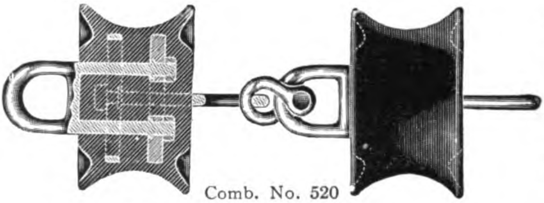

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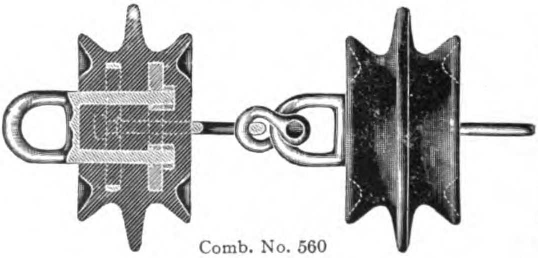

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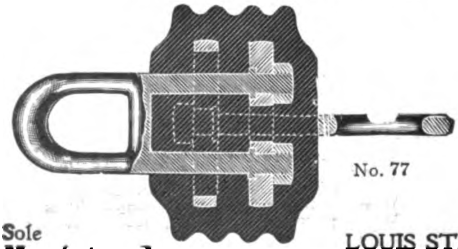

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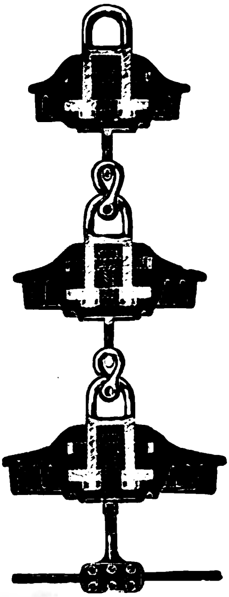

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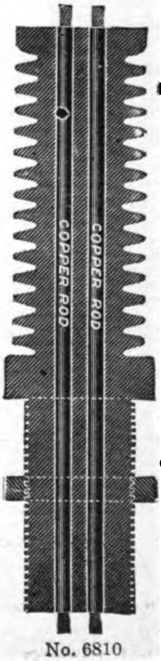

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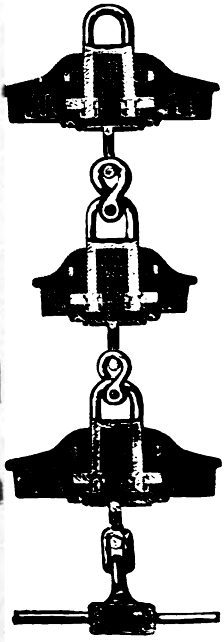

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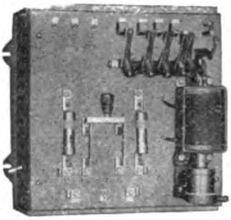

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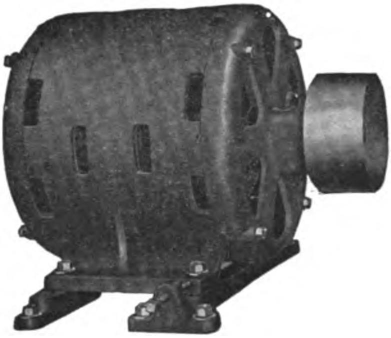

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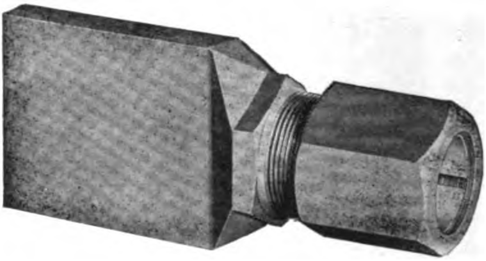

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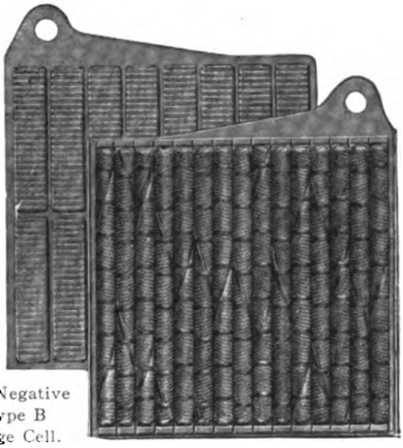

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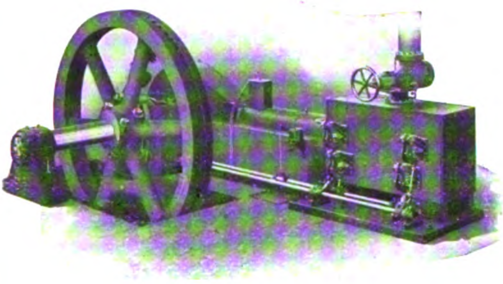

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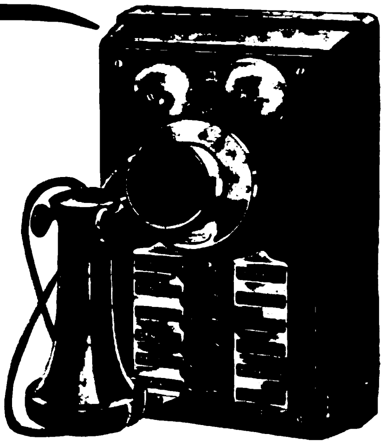

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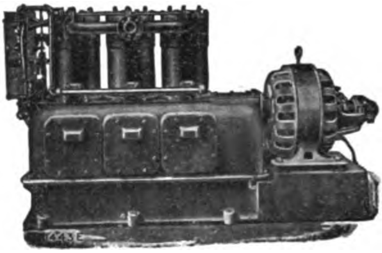

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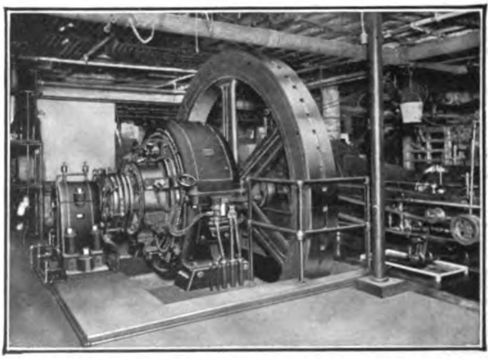

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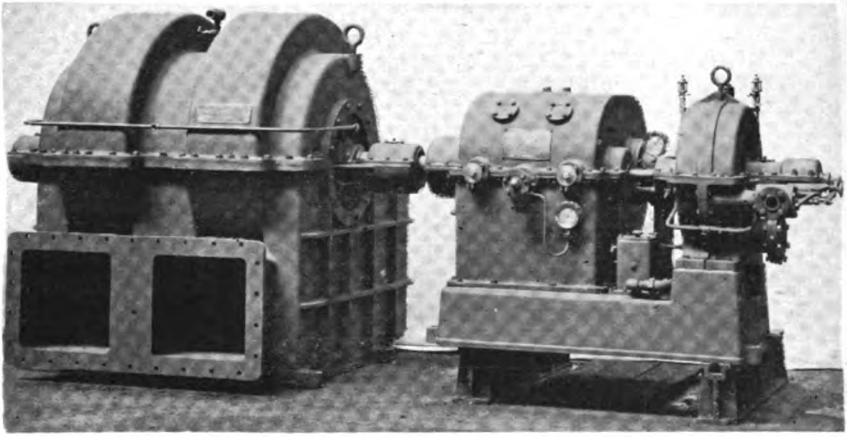

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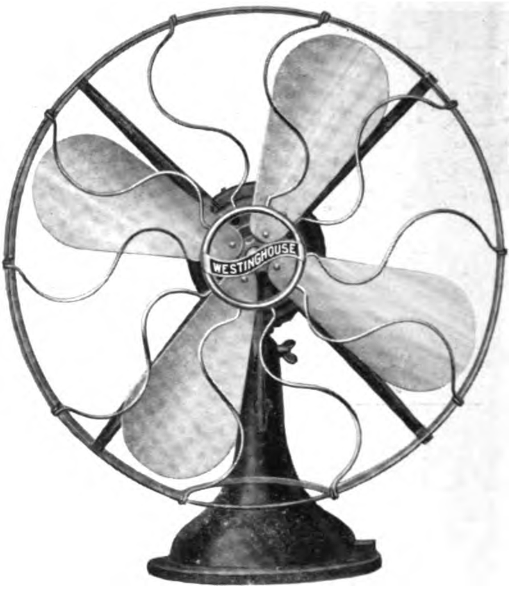

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